AIAA
S-113-2005

Standard

Criteria for Explosive Systems and Devices Used on Launch and Space Vehicles

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Abstract

This standard establishes criteria for design, manufacture, and performance certification of explosive systems and explosive devices commonly used on launch, upper stage, and space vehicle systems. The requirements contained in this specification are intended to serve as a universal set of tools for use by explosive system manufacturers and users during all phases of development and certification. This information may also be used for guidance during preparation of acquisition contracts and program-specific documents, and may be used for explosive system applications unrelated to space vehicles. These criteria, defined as standards, rules, tests, or measures of value by which an item can be judged, are applicable to explosive systems commonly used on launch, upper stage, and space vehicle systems as well as missile and other similar applications.

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Foreword

The purpose of this standard, developed by the AIAA Ordnance Committee on Standards (CoS), is to clearly define technical requirements, practices and expectations associated with ordnance systems and components to be used on launch, upper stage, and space vehicles. It is to be applied by Space and Missile Center as part of the technical baseline for acquisition, contracting and program management. To the greatest extent possible, requirements from past and existing government and military specifications and standards have been incorporated herein. In addition, the requirements herein include those generated as a result of lessons learned from launch and space vehicle programs as well as from other military and aerospace programs.

This standard will be updated and revised as appropriate to incorporate technological advances and innovations as well as lessons learned.

This standard may be tailored by the contractor, in consultation with the procuring authority, or may be replaced by another document from the government, industry, technical society, international community, or contractor provided the new document is comparable in rigor and effectiveness. Tailoring must be relevant and hold members of the government/industrial partnership appropriately accountable to sound technical disciplines.

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"Those who can not remember the past are condemned to repeat it."

George Santayana, (1863-1952)

Poet, novelist, Harvard professor of philosophy (1907-12)

Introduction

Explosive systems include components and assemblies that provide stimuli for initiation and propagation of explosive trains used to activate explosive devices. Explosive trains and devices are components or assemblies containing or operated by explosive materials. The latter are, by design, “one-shot” components that cannot be tested completely before use. Performance confidence of “one-shot” components can only be obtained by destructive tests of like samples from common production lots. This document describes criteria to certify safe and reliable performance of explosive systems and their “one-shot” components.

The criteria outlined in this standard are a composite of those verified by previous use in space and launch vehicle applications. Described are essential design characteristics, manufacturing controls, and methods for certifying performance, acceptance, qualification, and useful life.

Acronyms and Abbreviated Terms

BKNO3	Boron Potassium Nitrate
BNCP	Tetra-amine bis(5-nitro-2H-tetrazolato-N2) cobalt(III) perchlorate
CAD	Cartridge Actuated Device
CP	Penta-amine(5-cyano-2H-tetrazolato-N2) cobalt(III) perchlorate
DDT	Deflagration to Detonation Transition
EBW	Exploding Bridgewire Device
EED	Electro-Explosive Device
EFI	Exploding Foil Initiator
EFP	Explosively Formed Projectile
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
ET	Explosive Train
ETA	Explosive Transfer Assembly
F/CDC	Flexible Confined Detonating Cord
FLSC	Flexible Linear Shaped Charge
HBW	Hot Bridgewire Device
HE	High Explosive
HMX	His Majesty's Explosive, Cyclotetramethylene tetranitramine
HNS	Hexanitrostilbene
HVD/I	High Voltage Detonator/Initiator
LID	Laser Initiated Device
LPI	Lanyard Pull Initiator
LSC/A	Linear Shaped Charge/Assembly
MDF	Mild Detonating Fuse
MPE	Maximum Predicted Environment
MSDS	Material Safety Data Sheet
NDT	Non-Destructive Tests
NSI	NASA Standard Initiator
OTDR	Optical Time Domain Reflectometry

PETN	Pentaerythritol tetranitrate
RDX	Research and Development Explosive, Cyclonite or Cyclotrimethylene trinitramine
RF/I	Radio Frequency/Interference
S&A	Safe and Arm Device
SCB	Semi-Conductor Bridge
SDT	Shock to Detonation Transition
SMDC	Shielded Mild Detonating Cord
TBI	Through Bulkhead Initiator
TLX	Thin Layer Explosive
VISAR	Velocity Interferometer System for Any Reflector
ZPP	Zirconium Potassium Perchlorate

1 Scope

This standard establishes criteria for design, manufacture, and performance certification of explosive systems and explosive devices commonly used on launch, upper stage, and space vehicle systems. The requirements contained in this specification are intended to serve as a universal set of tools for use by explosive system manufacturers and users during all phases of development and certification. This information may also be used for guidance during preparation of acquisition contracts and program-specific documents, and may be used for explosive system applications unrelated to space vehicles. These criteria, defined as standards, rules, tests, or measures of value by which an item can be judged, are applicable to explosive systems commonly used on launch, upper stage, and space vehicle systems as well as missile and other similar applications.

2 Tailoring

For a specific program or project, the requirements defined in this standard may be tailored to match the actual requirements of the particular program or project. Tailoring of requirements shall be undertaken in agreement with the procuring authority where applicable.

Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards.

The criteria offered here are generic in nature; therefore, users are encouraged to consider tailoring these criteria to best fit individual applications. However, the tailored requirements shall achieve a level of verification equivalent to the baseline described herein. Rationale for each tailored requirement shall be established. If the requirements in this specification are not tailored by a contract, they stand as written.

3 Applicable Documents

The following applicable documents contain provisions that, through reference in this text, constitute provisions of this standard.

In the event of conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

AIA NASM 33540	*Safety Wiring, Safety Cabling, Cotter Pinning, General Practices for*
AIAA-2005-4039	*Advanced Applications of Statistical Methods in Testing of Energetic Components and Systems*
AIAA S-114	*Moving Mechanical Assemblies for Space and Launch Vehicles*
CFR, Title 49	*Code of Federal Regulations, Transportation*
MIL-STD-1168B	*Ammunition Lot Numbering and Ammunition Data Card*
MIL-STD-1751	*Safety and Performance Tests for the Qualification of Explosives (High Explosives, Propellants, and Pytrotechnics)*

4 Vocabulary

For the purposes of this document, the following terms and definitions apply.

Acceptor
explosive element that receives an initiating impulse from a donor charge

Batch
specific quantity of bulk explosive material prepared as a unit during manufacturing, chemical mixing or other processes and has been stored and handled as a unit

Booster Charge
explosive charge downstream of the first element of an explosive train that is used to cause initiation or detonation of a main explosive charge or to increase the energy output of the detonator or pyrotechnic input to the end item

Bridgewire
resistive element incorporated into the first element that converts electrical energy into heat or shock to cause initiation of an explosive charge

Cartridge
device that produces pressure which is used to actuate a mechanical device

Cartridge Actuated Device (CAD)
mechanical device that is actuated by the output from a cartridge

Closed Bomb
fixed volume test chamber to measure output characteristics of cartridges

Confined Detonating Cord (CDC)
linear explosive transfer assembly in which the explosive material is confined in a metallic sheath plus various layers of over-wrap materials intended to limit radial expulsion of detonation products, but sustain linear propagation of detonation waves

NOTE Explosive signal propagation velocity is typically 6000 to 8000 meters per second.

Conical Shaped Charge
explosive device with a concave metal liner which is converted into a jet of flowing material when detonated

Cook-Off Temperature
lowest temperature at which an detonation or deflagration of an explosive material occurs

Crossover
explosive connection or link between redundant explosive trains

Deflagration
very rapid combustion with a chemical reaction propagation velocity which is subsonic

Deflagration to Detonation Transition (DDT)
physical process in which the initial deflagration wave front in the material rapidly transitions into detonation

Detonation, High Order
chemical decomposition propagating through the explosive at a supersonic velocity such that a shock wave is generated

Detonation, Low Order
see deflagration

Donor
charge that transmits an explosive signal into a receptor

Dud
explosive charge or component that fails to fire or function upon receipt of the prescribed initiating stimulus

Electro-Explosive Device (EED)
first and most sensitive element of an explosive train which has a bridgewire and that transforms electrical energy into explosive output

Electrostatic Discharge
avalanche release of high voltage energy accumulated on the surface of solid objects

Expanding Tube Separation System
separation system that emits no contamination; the system includes detonating cord in a ductile metal tube and a structure containing geometrically controlled stress risers

Exploding Bridgewire Device (EBW)
electro-explosive device in which the bridgewire explodes when functioned; this explosion is used to directly initiate secondary explosive materials

Exploding Foil Initiator (EFI)
detonator that produces a shock output from high voltage acceleration of a metallic flyer plate that impacts the acceptor charge at supersonic speed

NOTE The EFI contains no primary explosive material.

Explosion
sudden conversation of potential energy into kinetic energy, heat, light, sound, and gas

Explosively-Actuated Device
device that converts explosive energy into mechanical work

Explosive Train (ET)
series of explosive components including the first element, explosive transfer assembly, and explosively actuated device

Explosive Transfer Assembly (ETA)
series of explosive components used to transfer the explosive signal from the first element to the explosively actuated device

Explosively Formed Projectile (EFP)
variant on the conical shaped charge in which the concave metallic liner is a hemisphere of very small curvature which is converted into a kinetic energy penetrator when detonated

Flexible Confined Detonating Cord (FCDC)
CDC whose over-wrap material allows for flexure of the cord for ease in handling and installation

Flexible Linear Shaped Charge (FLSC)
LSC with a ductile metal sheath which may be conformed to installation envelope

High Explosive
any chemical material in which the fuel and oxidizer are contained in the same molecule, the decomposition of which is a detonation

High Voltage Detonator/Initiator
see Exploding Bridgewire Detonator

Hot Bridgewire Device
Low voltage EED

Laser Initiated Device (LID)
first element containing secondary explosives that is ignited by laser energy

Linear Shaped Charge
linear explosive charge in a metal sheath whose cross-section is formed into a chevron shape

NOTE The chevron shape results in a jet of flowing sheath material expelled perpendicular to the linear propagation of detonation waves.

Mild Detonating Fuse (MDF)
thin ductile metal tube containing high explosives

NASA Standard Initiator
EED designed by the National Aeronautics and Space Administration

Percussion
method of initiating an explosive reaction by intentional sudden pinching, crushing or otherwise compressing explosive materials, as between a blunt firing pin and an anvil

Primary Explosive
Extremely sensitive explosive material that will detonate in response to normal environmental stimuli

Propellant
deflagrating explosive material whose output is essentially gaseous

Pyrotechnics
mixtures of inorganic fuels and oxidizers that can explode

Receptor
see Acceptor

Refurbish
partially replace components or elements in an explosive device or system to maintain reliability or extend service life

Repair
to perform work on a non-compliant device which renders it useable but not fully compliant with specification and/or drawing requirements

Rework
to perform work on a defective device which renders it useable and fully compliant with specification and/or drawing requirements

Rotor Lead
explosive charge contained in a can or in pellet form used within a device to transfer a detonation from one point to another downstream of the first element

Safe and Arm Device (S&A)
mechanical or electromechanical device that provides a moveable barrier within the explosive train downstream of the first element

Secondary Explosive
explosive material that is insensitive to heat or handling impact but will detonate under strong shock impulse

Semiconductor Bridge Initiator (SCB)
EED that uses a film semiconductor as the bridgewire element

Sensitivity
characteristic of an explosive that expresses its susceptibility to initiation by externally applied energy such as heat, mechanical shock, or other stimuli

Shielded Mild Detonating Cord (SMDC)
CDC contained within a rigid metal sheath to contain detonation products and increase robustness for handling and dynamic environments

Shock to Detonation Transition (SDT)
process occurring when a shock wave impacting a secondary explosive is not strong enough to initiate detonation directly but does cause a chemical decomposition that accelerates until it becomes a self-supporting detonation wave within the material

Squib
small first element device loaded with deflagrating material

Thermal Time Constant
characteristic time for heating up a bridgewire

Thin-Layered Explosive (TLX)
explosive transfer line in which the explosive powder is deposited on the interior walls of a hollow plastic tube

NOTE Explosive signal propagation velocity is typically 1200 to 1500 meters per second.

Through-Bulkhead Initiator (TBI)
device that propagates a high order detonation signal through an integral internal metal bulkhead leaving the bulkhead intact and initiating the downstream explosive materials

Trend Analysis Life Estimate
statistical method for shelf life estimation based on analysis of key performance parameters of an explosive device as a function of age

Velocity Interferometer System for Any Reflector (VISAR)
optical interferometer measuring device used to detect the velocity of a material accelerated by an explosive event

5 Design Requirements

An explosive system is comprised of an initiation system, first element, transfer system and explosively actuated device.

Explosive systems furnished under this specification, or under associated detail specifications, shall be flight accredited. Items are considered to be flight accredited if they satisfy all of the following conditions.

a) All components and systems meet the requirements of this section.

b) All components and systems have passed the margin and qualification test of Section 6.

c) Components are from a lot which meets the requirements of this section and that has passed the acceptance tests specified in Section 6. If prior lot acceptance testing has not met the requirements herein, testing and/or analysis shall be conducted to verify the compliance.

d) Components are from a lot that has verified service life for the scheduled operational use. Life extension testing is described in Section 6.

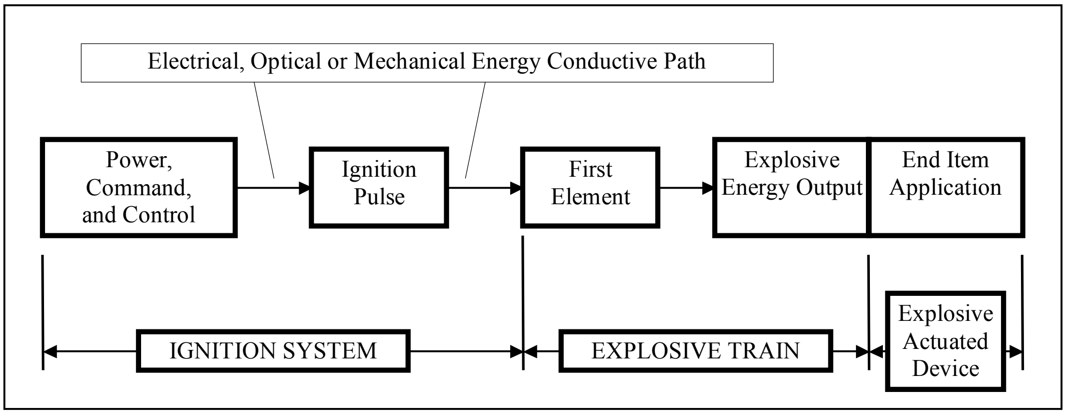

Figure 1 — Explosive System Flow Diagram

5.1 General Requirements

Explosive systems and components shall meet the following general requirements.

5.1.1 Environmental Determination

Explosive systems and components shall be designed to survive and perform intended functions during and after exposure to dynamic, thermal, humidity, pressure, electromagnetic, safety, or other environments that are predicted to be encountered during transportation, storage, and handling in use of the end item application.

The user of the explosive system or component shall determine the types of environments to be experienced throughout the service life in each application. These shall include predictions of magnitudes, durations, and margins of these environments as well as determinations if dynamic, thermal and/or humidity conditions may be combined into common tests. The user shall also ensure that all appropriate tests or analyses are performed.

5.1.2 Performance Requirements

Predicted performance requirements shall be updated to reflect actual device performance as demonstrated in margin and qualification testing. This shall include maximum and minimum limits on key performance parameters.

5.1.3 Safety

Explosive systems and components shall be designed to minimize risk to personnel, equipment, and facilities. Handling and installation procedures shall be formally documented and clearly identify operations where warnings and cautions are necessary to deter accidents. Safety requirements and procedures shall conform to all appropriate regulations of the countries, states and localities in which items will be transported, stored, and used. It is the responsibility of both user and manufacturer of explosive systems and components to ascertain which regulations apply to their products. The ability of explosive systems and first elements to survive electrical energy fields without premature initiation or degraded performance shall be verified by tests, inspections, and/or analysis.

5.1.4 Explosive System Fault Tolerance

Explosive systems shall be designed to be single fault tolerant.

For those applications where premature initiation may result in a catastrophic event, the explosive system should be designed to be two-fault tolerant. A catastrophic event is defined as loss of life, injury, or severe damage to equipment or facilities.

5.1.5 Design Life

Explosive systems and components shall be designed to have useful lives commensurate with the end item application. All explosive systems and components containing age sensitive materials shall be identified, and an age surveillance program for them shall be established. Design life shall be reassessed periodically to ensure that performance has not degraded with time.

5.1.6 Sealing

Explosive devices shall be sealed with a maximum allowable leak rate equivalent to 5 X 10^{-6} (atm · cm^3)/s of the gas medium used for the test. End item components or assemblies shall use environmental sealing techniques that prevent external elements or contaminants from interacting with explosive materials installed in them. Sealing shall be accomplished by fusion of metallic and/or non-metallic materials. Use of non-fused crimp-type joints shall not be used to effect the seal. Use of organic materials to enhance seal effectiveness is acceptable provided they are compatible with the explosive materials used.

Seal effectiveness shall be verifiable before and after exposure to thermal and dynamic environments described in destructive qualification and acceptance tests of this specification.

All interfaces in the explosive system shall provide adequate protection to preclude intrusion of water, salt, and other contaminants when exposed to worst case predicted environments. The designer should consider that a launch or space vehicle may remain on the launch pad through very extreme environments such as hurricanes and for a prolonged period up to one full year.

5.1.7 Electrical/Electromagnetic

5.1.7.1 General

Explosive systems shall be designed to operate without performance degradation or inadvertent firing when exposed to electrical energy environments such as electrostatic discharge, electromagnetic radiation, radio frequency interference, and lightning. An electromagnetic compatibility program shall be established to ensure resistance to these environments. A key consideration is that the radar power used at the launch sites has been increased significantly in recent years.

5.1.7.2 Electrostatic Discharge

Explosive systems and components shall be designed to survive external applications of an ESD environment. Protective features shall be included to prevent premature initiation of first elements or deactivation of safety inhibits. All ESD-sensitive components shall be shielded or otherwise protected from the environment. Analyses shall confirm that there are no sneak circuits or unplanned capacitance discharges that could cause initiation. Verification of effectiveness of these features shall be based on inspection, test, and analysis.

First elements used in explosive systems that are potentially susceptible to premature initiation or degraded performance by an ESD energy field shall be tested to verify survivability.

5.1.7.3 EMC

The explosive system power, command, and control electrical circuitry shall be designed to limit generation of electromagnetic fields in sensitive components to a level at least 20 dB below the no-fire rating of the first element. The explosive system shall also be capable of shielding these sensitive components to the same levels noted above when exposed to externally generated electromagnetic fields. Control circuits shall be designed to limit the power level at any inhibit to at least 6 dB below the minimum activation power.

5.1.7.4 RF

All explosive systems and first element designs shall be capable of surviving exposures to externally applied RFI fields anticipated during transportation, storage, and use of the end item application and with sufficient margin without premature initiation or degraded performance.

5.1.7.5 Lightning

Explosive systems shall be designed to preclude premature activation due to electrical energy fields generated within the system by exposures to lightning strikes. Assessment of survivability may be accomplished by inspection and analysis of the explosive system and components design.

5.1.8 Materials

5.1.8.1 Selection of Parts, Materials, and Processes

The parts, materials, and processes shall be selected and controlled in accordance with the contractor established and documented procedures to satisfy the requirements specified herein. The selection and control procedures shall emphasize quality and reliability to meet the mission requirements and to minimize total life cycle costs for the applicable system. An additional objective in the selection of parts, materials, and processes shall be to maximize commonality and thereby minimize the variety of parts, related tools, and test equipment required in the fabrication, installation, and maintenance of the vehicle. The parts, materials, and processes shall be selected to meet the functional, performance, safety, reliability, contamination, and strength requirements of the end item or the explosive device during its design life, including all environmental degradation effects.

5.1.8.2 Fracture Toughness

Materials selection shall include assessment of susceptibility to cracking due to shock loads or shock loads combined with low temperatures.

5.1.8.3 Fungus Resistance

Inherently fungus-inert materials shall be used.

5.1.8.4 Material Compatibility

Dissimilar materials, including explosives and adhesives, in contact with each other shall be evaluated for compatibility. In addition, materials exposed to the external environment shall not react when exposed to vehicle propellants, fluids, and gases.

5.1.8.5 Age-Sensitive Material

Age-sensitive materials used in an explosive system or component shall be identified, assessed, and documented as to their support of design life of the system or component.

5.1.8.6 Energetic Materials

Explosive materials used in explosive trains shall meet the performance and safety requirements of this specification and supporting documentation shall be readily available. Proprietary or other unique compositions that may result in superior performance, increased reliability, or improved safety may be used if components and systems containing them pass performance tests defined in this specification and conform with the safety regulations.

5.1.8.6.1 Primary Explosives

The use of primary explosives shall be minimized consistent with achieving reliable performance.

5.1.8.6.2 Upper Temperature Limit

The decomposition, cook-off, and melting temperatures of all explosives shall be at least 30°C higher than the maximum predicted environmental temperature to which the material will be exposed during storage, handling, installation, transportation, launch, flight, or orbit. Thermal shielding, if proven to be effective, may be adopted.

5.1.8.7 Metals

5.1.8.7.1 Dissimilar Metals

Dissimilar metals shall not be used in intimate contact with each other unless suitably protected against electrolytic corrosion.

5.1.8.7.2 Corrosion Resistance

Metals shall be corrosion resistant, or shall be suitably treated to resist corrosion when subjected to the specified environments including humid or corrosive environments during manufacture, installation, storage, handling and operation.

5.1.8.7.2.1 Protective Coatings, Finishes and Plating

Materials selections shall ensure that completed components are resistant to corrosion that interferes with mechanical, thermal, or electrical performance.

Cadmium and zinc platings shall not be used.

Plating with pure metals such as tin shall consider the detrimental effects of whisker growth.

5.1.8.7.2.2 Stress Corrosion

Materials selections shall ensure that completed components are resistant to stress corrosion cracking, and brittle fracture failure modes, and preclude failures induced by hydrogen embrittlement.

5.1.8.7.3 Heat Treatment

All materials and associated heat treatments shall be approved by the procuring authority before use.

The selection of alloys and heat treatments shall be compatible with the stress and temperature environments.

High strength steel parts heat treated at or above 1241 MPa ultimate tensile strength shall include appropriate test specimens from the same heat treat of material as the part. These test specimens shall accompany the parts through the entire fabrication cycle to ensure that the desired properties are obtained.

5.1.8.7.4 Galling

Threaded and moving interfacing metals and lubricants shall be selected to preclude galling during assembly or disassembly.

5.1.8.8 Non-Metallic Materials

Materials selected shall survive thermal and dynamic environments and demonstrate performance as described by tests in this specification. Use of shock-sensitive materials, such as graphite epoxy composite, in close proximity to explosive-actuated devices shall be avoided.

5.1.8.9 Lubricants

Lubricants shall not come in contact with explosive materials during manufacture, storage, and use.

Lubricants shall be selected with consideration given to corrosion, outgassing, temperature limits, operation in a vacuum, creep properties, effect of long term storage, and compatibility with other lubricants and materials.

5.1.8.10 Adhesives and Sealants

Adhesives and sealants used in explosive devices shall be compatible with the explosives contained therein.

5.1.9 Human Engineering

Explosive systems shall be ergonomically designed and developed to preclude human error, incorrect installation and assembly.

System interfaces and/or installation shall be designed to preclude inadvertent interchange of the items or interconnections that could cause possible malfunction. Tabs, shoulders, different thread sizes, and different electrical connector clocking may be employed.

5.1.10 Contamination

5.1.10.1 Design

Explosive devices shall not emit any products that will be detrimental to the safety and performance of the vehicle.

Performance and safety of explosive devices shall not be adversely affected by contamination from the environment.

5.1.10.2 Manufacturing, Handling and Storage

The system devices shall be manufactured, packaged, handled, stored, and installed in such a manner that supports contamination requirements for the launch vehicle or spacecraft.

5.1.10.3 Combustion Products

There shall be no deleterious contamination resulting from the function of the explosive system. If a component design cannot ensure the containment of generated gas and contaminants, the component shall be mounted in such a manner as to protect optical sensors and thermal control surfaces.

5.1.11 Recovering from Environmental Exposure

The design documentation shall identify all explosive components that cannot be reworked to specification(s) after exposure to certain environmental conditioning that could create permanent chemical or physical change.

For example:

- Explosive devices or components that fail gross leak check (using liquid as the test medium) shall not be reworked or repaired by resealing the leak joint by welding, application additional of sealant or any other method.
- Gross leaked TLX shall not be reworked as the test may cause powder redistribution inside the tube.

5.1.12 Mechanical Components

Requirements for mechanical components not referenced herein are presented in AIAA S-114-2005.

5.1.12.1 Fasteners

A minimum engagement of five full threads is required for threaded attachments or, for through bolts, the threaded end shall protrude a minimum of two full threads beyond the end of the nut.

Screw sizes smaller than 3.6 mm (No. 8) in diameter shall be avoided, where practicable.

Where there are areas that may be sensitive to debris generated during assembly of threaded parts, blind holes should be considered. Tolerances shall be controlled to prevent threaded parts from bottoming in blind holes.

5.1.12.2 Locking Devices

Positive locking devices shall be utilized on all threaded interfaces and fasteners.

Preferred locking devices are safety wire, bent tab washers, cotter pins, self-locking threads, or threads with locking plastic inserts. Safety wiring, cables, and cotter pins shall comply with requirements of NASM33540 or equivalent document.

Self-locking interference fit threads shall not be used.

When self locking features are used, the screw length shall be sufficient to fully engage the locking feature at worst case tolerances. If self-locking features are to be re-used, an allowable range of run in torque and the maximum number of re-uses shall be specified.

Use of thread locking compound is acceptable and shall meet all compatibility requirements of this specification.

5.1.12.3 Stops

Mechanical stops or shoulders and associated attachments shall be designed to a structural yield factor of safety based on static analysis of forces that occur upon full extension, actuation, or stopping of moving assemblies. A feature that dissipates energy and /or provides retention may be provided.

5.1.13 Explosive Material Output

Some explosive output properties are specified as minimum values. In some cases a more brisant material or a faster burn time may not be suitable in its intended application. In certain applications either the maximum and minimum values of the explosive performance parameters must be defined or the application shall accommodate all expected variations in explosive properties.

The performance of an explosive system must be coordinated with the user. A high output from the explosive device in staging application may deform the adjacent component of vehicle that can cause a failure.

5.1.14 Mechanical Integrity

Components, when installed into their system interfaces, shall be designed to withstand at least 1.5 times maximum internal pressure resulting from functioning.

5.1.15 Electrical Bonding

Metallic components of the explosive system which are physically connected shall have measured direct current resistance values as follows:

a) electrical firing circuit housing to structure: Less than 2.5 milliohms;

b) safe and arm housing to structure: Less than 10 milliohms;

c) non-electrical ordnance component to non-electrical component or to structure: Less than 1 ohm;

d) non-electrical, linear ordnance component end to end (LSC, FLSC, FCDC, etc): Less than 10 ohms.

5.1.16 Manufacturing and Quality

5.1.16.1 General

Explosive components and systems shall be manufactured in accordance with established processes and criteria that can be verifiable by established quality control methods. Development testing shall validate use of any innovative manufacturing technique before subjecting manufactured items to tests of this specification. Quality of all manufactured items shall be assessed and results documented. Traceability of critical materials, components and processes shall be documented for each manufacturing lot.

5.1.16.2 Configuration Control

The manufacturing of explosive devices shall be accomplished in accordance with documented requirements, procedures and process controls that ensure the reliability and quality required.

Manufacturing and process controls including flow charts and referenced specifications, procedures, drawings, and supporting documentation establishes a supplier-controlled qualified baseline to ensure subsequent production items are equivalent in performance, quality, configuration, and reliability to initial production items used for qualification. This baseline shall be documented and controlled by the supplier.

Any change to this qualified baseline shall be documented by the supplier and shall be submitted to the procuring authority for evaluation. These changes, which shall be controlled by the supplier, provide the basis for flight accreditation of subsequent production lots.

5.1.16.3 Production Lot

Explosive items shall be manufactured and tested in individual production lots during the various stages of manufacturing to assure that all items in a production lot are assembled to the approved configuration during the same time period using the same production materials, tools, methods, personnel, and controls.

Any interruption of a continuous manufacturing process shall be identified by the supplier. Units on either side of the interruption shall be considered to belong to sub-lots. In-process inspections and tests and acceptance testing shall verify that all sub-lots demonstrate homogeneous attributes and performance. If this is true, the subgroups shall henceforth considered to belong to one lot.

Each production lot shall be loaded with explosive materials manufactured, handled, stored, processed, and tested as a single lot. Critical non-explosive materials shall also be lot controlled. Materials and parts which must be single lot controlled shall be identified for each design and properly controlled during lot manufacturing.

5.1.16.4 In-process Tests and Inspections

The fabrication process shall provide for in-process tests and inspections. Documentation describing results of tests and inspections performed during manufacture of components containing or operated by explosive materials shall be made available to end item users prior to or upon delivery of the items. These in-process test and inspection records shall be used as a means to measure validity of post-delivery tests and inspections of like parameters.

5.1.16.5 Refurbishment

Explosive components shall be considered one-shot items. They shall not be refurbished for flight use after firing.

5.1.16.6 Identification and Marking

Explosive systems and components shall be permanently identified, to include as a minimum part number, serial number and manufacturer identifier.

5.1.16.6.1 Not For Flight Marking

Items not suitable for flight use, which could be substituted for flight or flight spare hardware, shall be red tagged or striped with a unique color paint, or both to prevent such substitution. The red tag shall be conspicuous and marked "NOT FOR FLIGHT".

5.1.16.6.2 Lot Number

Lot numbers shall be assigned to each production lot in accordance with MIL-STD-1168.

5.1.16.6.3 Serial Number

Components or assemblies requiring control shall be assigned a unique (non-repeating) serial number for each unit manufactured.

This serial number shall be assigned at an appropriate point in the manufacturing flow. This serial number shall be permanently marked on the item.

5.1.17 Explosive Hazard Data

Explosive hazard data shall be maintained for each component, subassembly, and assembly, as appropriate. Data shall include chemical compositions and weights, net explosive weight, safety information and may be contained in documents such as MSDS, Hazardous Component Safety Data Statements, or Competent Approval Authority letters. Data shall be updated as configuration changes are made and traceable to configuration.

5.1.17.1 Explosive Hazard Classification

The explosive component, subsystem, or system manufacturer is responsible for obtaining documentation that defines appropriate transportation and handling classification for each configuration produced for the countries, states, or localities through which it will be transported. The manufacturer shall include this documentation and any supporting information with the explosive component data package.

5.1.17.2 Material Safety Data Sheet

The supplier shall provide MSDS or equivalent to address all hazards of the explosive component, subsystem, or system being delivered.

5.1.17.3 Ammo Data Card

When specified, an Ammunition Data Card, or a copy, prepared by the supplier, shall accompany each shipment of explosive devices or assembly of devices.

Ammo data cards shall meet the requirements of MIL-STD-1168.

5.2 Margin Requirements

5.2.1 General

All interfaces in the explosive system shall include verified margin between donor component and acceptor component. Examples of this include voltage/current applied to EEDs, Laser light energy applied to LIDs, EED output to booster charge, detonation transfer between devices and through bulkheads, pressure cartridge output to cartridge actuated device, and severing/penetrating device output to target.

Individual devices with internal interfaces must be designed and verified to have margin between donor material output and acceptor material input threshold.

5.2.2 Initiation System to First Elements

Tests and analyses shall be used to verify the amount of positive margin between initiation system worst case output parameters and ignition threshold limits of interfacing first element. All-fire limits of first elements should be determined during tests and analysis described in Section 6.

Initiation system output parameters shall be maintained during margin testing.

5.2.2.1 Electro-Explosive Device

The initiation system shall be designed such that the minimum stimulus applied to each device in the system is equal to or greater than 2.0 times the all-fire level of the device. In the case of low voltage EEDs, current applied to each EED in the system is equal to or greater than 2.0 times the statistical all-fire or 1.5 times the sure-fire current, whichever is greater.

5.2.2.2 Laser Initiators

The design of the laser initiation system shall provide margin in the initiation energy/power to compensate for temperature sensitivity and optical attenuation due to misalignment, contamination of optical surfaces and nuclear radiation darkening.

5.2.2.3 Mechanical Initiators

For this type of system, minimum system energy level when the firing pin strikes the first energetic element, e.g. primer or stab initiator, shall be at least 2 times the statistical all-fire level for the device; maximum system output shall be less than maximum level at which the device is verified to perform acceptably. For primers and stab initiators, the statistical all-fire is defined as drop weight times the sum of mean firing height plus 5 standard deviations.

5.2.3 Booster Charges

Booster charges (deflagrating or detonating), if employed in ET designs that require additional explosive elements downstream of the first element, shall be designed to enable transfer of energy to the next element in the train or to the explosive-actuated device. If the booster charges are an integral part of the first element assembly, they shall be included in the application using first element tests. Booster charge designs that are not integral with the first element shall use tests for explosive energy transfer elements.

5.2.4 Explosive Energy Transfer

5.2.4.1 General

Tests and analyses shall be used to validate that a positive margin of at least 1.20 exists between first element minimum output energy and minimum input energy requirements of the interfacing ET. Tests shall also verify that a margin of no less than 1.20 exists between the maximum first element energy output and the upper limit of acceptable input energy of the interfacing ET. Explosive charge weight alone cannot be used to predict energy output.

5.2.4.2 Detonation Transfer

5.2.4.2.1 Transfer Between Components

Energy transfer performance margins tests shall be conducted on all elements of an ET where transfer across a discontinuity, or gap, in the ET is required. This testing shall consider any material that is in the design detonation path. Axial and angular misalignment between donor and receptor shall also be considered.

Methods for verifying detonation transfer margin are presented in Section 6.

5.2.4.3 Transfer Through Bulkhead

All detonation transfer interfaces through solid material shall perform with margin when the solid material thickness is increased to 20% more than design maximum and with nominal donor and receptor charges. If the solid material is to remain un-ruptured during nominal performance, the interface shall perform without rupture when the solid material thickness is decreased to 80% of design minimum and with nominal donor and receptor charges.

Margins shall be verified through a bulkhead that is 0.80 times the minimum specified thickness used in the end item application. These tests shall demonstrate structural integrity of the bulkhead during and after initiation of the receptor charge.

5.2.5 Cartridge Actuated Device

All CADs shall perform within specified limits when actuated by a single cartridge having 80% or less of the minimum specified cartridge output.

All CADs shall perform within specified limits when actuated by dual cartridges having at least 120% of maximum specified cartridge output. The CAD shall not rupture under these conditions.

All CADs that are required to operate under a load, shall not rupture when functioned both with two nominal cartridges in the no-load condition.

All CADs which are required to operate under a load, shall perform within specification limits with one nominal cartridge when the load is increased to 50% more than the maximum predicted operating load.

If there is any possibility that the CAD may function in a locked shut condition, the CAD shall not rupture when fired with two nominal cartridges and the internal moving components restrained so no motion is possible.

5.2.6 Severing and Penetrating Device

Performance margins for explosive-actuated devices used for severing or penetrating shall be determined by tests and analyses. For applications requiring severance or penetration of a single layer of homogeneous material substrate, performance margins shall be demonstrated using nominal charges, positioned at maximum standoff, directed at a substrate with a thickness 1.5 times the maximum thickness to be used in the end item application. For applications requiring severance or penetration of multiplied composite substrates performance margins shall be demonstrated using nominal charges, positioned at maximum standoff, directed at a substrate with a thickness 2.0 times the maximum thickness to be used in the end item application. Substrate materials shall be identical to those to be used in the end item application. Test fixtures shall simulate the end item application, including all materials in contact with it, to the extent practical.

Margin may be demonstrated for severing and penetrating devices either by firing a down-loaded charge against a nominal target or a nominal charge against a margin target. In the first case, a charge that is loaded at 67% of minimum design charge weight is fired at a nominal target with maximum design standoff from the target. In the second case, a nominal charge is fired against a target that is 50% thicker than maximum design thickness.

These performance margins also apply to non-thrusting expanding tube separation systems.

5.2.7 Fracturing Devices

Devices that rely upon the fracturing of a load carrying web, membrane, or annulus, such as those in frangible nuts and explosive bolts, shall meet the margin requirements of 5.2.4.1. However when it is impractical to vary the explosive charge weight, a single nominal explosive charge shall be capable of fracturing a device with an area at least 20% greater than the maximum design break area. Protective covers or other critical vehicle features shall withstand the effects of a device with a break area of at least 80% of design minimum break area when fired by two nominal explosive charges.

5.2.8 Linear Thrusting Joints

Linear thrusting joints shall be capable of performing their end function when actuated by an explosive charge that is no greater than 80% of the minimum specified explosive charge weight, and when actuated by an explosive charge weight that is at least 120% of the maximum charge weight, with no increase in the initial free volume.

5.3 System Design Requirements

5.3.1 General

Explosive systems are comprised of initiation system, first element and transfer system and explosively actuated device.

System design shall also consider higher level system needs such as simultaneity, differential thrusts, shock levels, dynamic effects, event sequencing, etc.

All explosive devices shall be designed so as not to require any scheduled maintenance or repair during their service life. The designs shall accommodate easy installation, testing, or replacement at the user facility.

5.3.2 Interfaces

Each interface of the explosive system shall be designed to meet the margin requirements of Section 5.2.

5.3.3 Redundancy

Crossover boosters shall not compromise redundancy requirements.

All explosive functions shall be designed so that a failure of any single explosive element to operate will not cause a failure of the function. Exceptions will be evaluated on a case-by-case basis.

Acceptable redundancy can be achieved by providing two ET inputs, one at each end of a linear device. Acceptable redundancy can also be achieved using dual inputs to a single explosively actuated device.

Dual bridgewire EEDs are not considered to be redundant within themselves.

Redundant explosively actuated devices shall be used to perform a function. When vehicle design considerations necessitate the use of a single device to perform a function, dual inputs shall be used to initiate/actuate the device. Firing of either or both inputs shall provide operational success. Firing of the first input shall not compromise function of the redundant input.

5.3.4 Reliability

The reliability design requirements shall assure that the overall system reliability requirements are met under the most severe extremes of acceptance testing, storage, transportation, preflight testing, and operational environments. The overall design goal of explosive system reliability shall be a minimum of 0.995 at the 95% confidence level. To achieve this goal, higher reliability shall be apportioned to all components in the system.

5.3.5 Initiation System

5.3.5.1 General

Initiation systems utilize electrical, optical, or mechanical energy that is applied to the first element of the ET. These systems shall be controlled to ensure reliable initiation and to prevent inadvertent or premature initiation of the system. Requirements in this section apply when the system is subjected to all anticipated environments to include as a minimum dynamic, thermal, electromagnetic/RF, and humidity.

Initiation systems are powered, controlled and commanded by inputs from the vehicle. The inputs are converted into electrical, optical or mechanical energy stimuli that are applied to the first element. The limits of these stimuli shall be controlled and inhibited. Controls ensure reliable initiation whereas inhibits prevent inadvertent or premature initiation.

The explosive system shall be designed to ensure that connecting and disconnecting the first element will not cause inadvertent initiation of the first element.

5.3.5.2 Electrical System

5.3.5.2.1 General

Ungrounded firing output circuits shall be shorted together and connected to structure by static bleed resistors. If the resistor(s) remain connected to the initiation circuit in the armed mode they shall have a minimum resistance of 10 K-ohms.

5.3.5.2.2 Power Source

Separate and dedicated power distribution points shall be used for the electro-explosive system firing sources. A firing source can share the same power source with other loads, but all currents flowing from the firing source point shall be for firing circuits only.

If the host vehicle supplies power to the firing source circuit, one of the following options shall be employed.

a) The return side of the firing source circuit shall not be grounded on the payload side of the interface, and shall be isolated from payload structure by at least 10 K-ohms measured at 1.5 times the bus voltage or greater, or equivalent isolation.

b) Isolation transformers shall be employed in the firing source circuit to provide at least 10 K-ohms isolation between the payload return circuit and the host vehicle return circuit when measured at 1.5 times the bus voltage or greater.

5.3.5.2.3 Wiring

Electrical wiring within an explosive system and those to be used for explosive system testing shall be isolated using low inductance materials and be twisted shielded pairs of conductors, flex circuits, or coaxial cables.

The explosive system chassis or structure shall not be used as the return side of any circuit. The return path, on all circuits, shall be selected to minimize voltage buildup and transients on the firing circuit return with respect to the single point ground.

Any grounding of the firing circuits shall be done at one point only. Ungrounded firing output circuits shall be connected to structure by static bleed resistors.

Wiring cable shielding shall be terminated on the circumference of the back-shell of each connector used.

The design shall preclude sneak circuits and unintentional electrical paths.

5.3.5.2.4 Shielding

The firing circuit including the electro-explosive device shall be completely shielded, or shielded from the EED to eliminate RF energy into the shielded portion of the system. Isolators shall provide 20 dB attenuation (regardless of source and load impedance) at all frequencies of the expected electromagnetic environment. The adequacy of the RF protection provided by these isolators can also be demonstrated by test or analysis for each specific usage.

Cable shielding shall provide a minimum of 85% of optical coverage. For all other elements of the shielding there shall be no gaps or discontinuities, including the termination at the back faces of the connectors, or apertures in any container which houses elements of the firing circuit.

Shields shall not be used as intentional current carrying conductors, but may be multiple-point grounded to structure.

5.3.5.2.5 Cables

Electrical cables may be fabricated such that several electro-explosive system circuits are contained in a common shielded cable bundle, provided that the isolation requirements are maintained.

There shall be no splices used to join elements of cables.

A connector shall be provided wherever mating or de-mating of a circuit is required.

All cable runs shall be routed to dissipate electrical charge build up.

5.3.5.2.6 Isolation

To ensure that DC electrical circuits to the initiating device do not inadvertently cause a ground fault and to control leakage currents, the circuits shall be isolated from adjacent structures by at least one mega-ohm.

Firing circuits that do not share a common fire command shall be electrically isolated from one another such that current on one firing circuit does not induce a current greater than 20 dB below the no-fire current level in any firing circuit.

Control circuits shall be electrically isolated so that a stimulus in one circuit does not induce a stimulus greater than 20 dB below the no-fire current level in any firing circuit.

5.3.5.2.7 Physical Separation

Firing output circuits shall be physically separated from all other types of circuits.

5.3.5.2.8 Electrostatic Protection

EEDs shall be protected from electrostatic hazards by the placement of resistors from line-to-line and from line-to-ground (structure). The placement of line-to-structure static bleed resistors does not violate the single point ground requirements as long as the parallel combination of these resistors are 10 kΩ or more.

5.3.5.2.9 Monitor Circuits (Portable or Built-in)

Application of operational voltage to the monitor circuit shall not compromise the safety of the firing circuit nor cause the electro-explosive system to be armed.

Monitoring currents shall be limited to 50 mA or one-tenth of the no-fire current level of the EED, whichever is less.

Test equipment that applies current to the bridgewire shall be designed to limit the current to 10 mA.

5.3.5.2.10 Payload Interface Controls

Command and control interfaces with the host vehicle that are used for any arming or firing functions in the payload shall not be actuated or triggered by return currents flowing in the host vehicle or payload structure.

5.3.5.2.11 Connectors

5.3.5.2.11.1 Type

All connectors used with the EEDs shall:

a) be approved by the procuring authority;

b) have a stainless steel shell or suitable electrically conductive finish;

c) complete the shell-to-shell keyway engagement connection before the pins connect;

d) provide for 360 degree shield continuity.

5.3.5.2.11.2 Pin Assignment

The circuit assignments and isolation of pins within any electroexplosive system circuit connector shall be such that any single short circuit occurring as a result of a bent pin or contamination will not result in more than 50 mA or one-tenth of the no-fire current whichever is less applied to any EED.

There shall be only one wire per pin, and in no case shall a connector pin be used as a terminal or tie-point for multiple connections.

Spare pins are prohibited in connectors which are part of firing output circuitry.

5.3.5.2.11.3 Locking

Connectors shall be selected such that they are not subject to de-mating when exposed to the maximum qualification environments.

5.3.5.2.11.4 Mismating

Firing circuit connectors shall not be capable of being mismated.

5.3.5.2.11.5 Separate Connectors

Where redundant circuits are required to meet fault tolerance requirements, separate output connectors shall be used.

5.3.5.2.12 Firing Switches and Relays

Electromechanical and solid state switches and relays shall be capable of delivering the maximum firing circuit current for a time interval at least 10 times the duration of the maximum firing pulse.

These switches and relays shall be capable of sustaining the post-fire short circuit current without exceeding any steady state or transient limits of the solid state or electromechanical device used.

The use of a solid-state device to provide isolation between the firing circuit and ground/structure requires specific approval from the procuring authority.

Relays that are series inhibits shall be mounted on axes to minimize the potential of vibration or shock activating more than one of the relays simultaneously.

5.3.5.2.13 Insulation Resistance

All current carrying components and conductors shall be electrically insulated from each other and system ground.

After exposure to environments, the insulation resistance between all insulated parts shall be greater than 2 MΩ for low voltage EEDs or 20 MΩ for high voltage EEDs.

5.3.5.2.14 Post Fire Short Circuit Protection

Electro-explosive systems shall include positive protection from line-to-line and line-to-ground shorts that may develop within a fired EED. The system shall be designed to open firing switches after firing in a specified time, incorporated with current limiting serial resistor, or shall incorporate an EED with a specified minimum open circuit resistance after firing.

5.3.5.2.15 Safe and Arm Plug Device

Firing circuits that use arming plugs shall be designed to electrically interrupt the EED side of the firing circuit. They shall provide for the ESD protection of the EED with the arm plug removed. This protection may be achieved by installing a safe plug in the arm plug receptacle or by intrinsic design of the firing circuits. If a safe plug is not required, a suitable conductive cap shall cover the arm plug receptacle.

Arm and safe plugs or caps shall be designed to be positively identifiable by color, shape and name. The natural (unpainted) body color of the arm llug is required. The safe llug or cap should be green and shall have a red "REMOVE BEFORE FLIGHT" streamer attached. They shall be marked arm and safe, respectively.

The design of the device and the firing circuit shall ensure easy access for plug installation and removal during assembly and checkout in all pre-launch and post-launch facilities.

Monitor and control circuits shall not be routed through safe plugs.

5.3.5.3 Low Energy Electrical System

Low energy electrical systems, which have a power source based on either battery, dedicated power bus, or a capacitor, shall be designed such that the amplitude and duration of the firing current or voltage meet the margin requirements of Section 5.2.

Maximum system output shall be less than maximum level at which the device is verified to perform acceptably. During system power on and power off checks, during all switching operations, during system exposure to range electromagnetic/RF energy, and considering bent pins in connectors, the maximum voltage / current applied to the EED shall be verified to be limited to no more than 1% of EED no-fire level or 10 mA, whichever is less.

Electrical circuit designs used for power, command and control of the ignition system should be fail-safe and have validated an ability to prevent premature EED activation. The circuitry should preclude narrow band high amplitude energy pulses near EED ignition thresholds during all switching operations. Measurements during switching operations should be made as part of system validation.

5.3.5.4 High Energy Electrical System

This type of initiation system uses above 500 VDC capacitive discharge source to initiate Exploding Bridgewire devices, and Exploding Foil Initiators devices. For this type system, minimum system capacitor energy shall be at least 2 times the statistical threshold level for the device; maximum system output shall be less than maximum level at which the device is verified to perform acceptably. The capacitor used in the system shall have a capacitance at least as great as that used to determine device threshold level. System inductance and resistance shall be bracketed by those used during determination of device threshold level.

Power, command, and control circuits of the initiation system shall be failsafe and shall have a validated ability to prevent premature device initiation. During system power on and power off checks, during all switching operations, during system exposure to range electromagnetic/RF energy, and considering bent pins in connectors, the maximum voltage / current applied to the EED shall be verified to be limited to no more than 1% of device no-fire level.

High voltage ignition system designs shall provide voltage inputs to the EED that are at least 20% greater than EED all-fire ratings using capacitance values equal to or greater than those specified by the EED. These criteria should be verified by tests during development, acceptance and qualification of the ignition system design. The system should have validated an ability to provide the outputs specified when subjected to dynamic and thermal environments anticipated before or during use in the application. Electrical circuitry designs used for power, command and control should be fail-safe and have validated their ability to prevent premature EED activation. Validation that maximum energy inputs do not exceed EED design limits should also be done.

A safety device shall provide a positive interruption of the capacitor charging circuit and the trigger circuit. In addition, a provision capable of gradually discharging the firing system capacitor circuit shall be provided.

5.3.5.5 Optical

This type of initiation system uses laser energy to initiate the LID. The minimum system energy level shall be at least 2 times the statistical threshold level for the device; maximum system output shall be less than maximum level at which the device is verified to perform acceptably. The laser used in the system shall produce a pulse intensity and duration at least as great as that used to determine device threshold level.

The optical interface with the fiber optic cable shall be designed to minimize the alignment loss and to protect against dust and moisture contamination.

The optical cable light transmission can be degraded temporarily during, or permanently following, high and low temperature exposure. Each lot of fiber shall be lot accepted to verify transmissibility. The fiber optic cable attaching to the LID shall be capable of surviving the same environmental exposures as the device itself.

Power, command, and control circuits of the initiation system shall be failsafe and shall have a validated ability to prevent premature device initiation. During system power on and power off checks, during all switching operations, during system exposure to range electromagnetic/RF energy, and considering bent pins in connectors, the maximum energy applied to the LID shall be verified to be limited to no more than 1% of device no-fire level.

If a low energy end-to-end test is to be performed with the LID connected, the test shall use a different wavelength than that used by the firing laser and shall apply no more than 1% of the LID no-fire threshold when considering all single failure modes of the system.

Electrical circuit designs used for power, command and control of optical ignition systems should be fail-safe and have validated their ability to prevent premature laser activation.

A system level built-in-test shall be utilized, in which a checkout laser pulse at a wavelength different from that of the firing laser pulse and the LID window design with wavelength transmission discrimination coating is preferred for the safety. A temperature off-set design shall be adopted in the laser firing package. The optical energy fluence in the fiber depends on the fiber core diameter and its numerical aperture, and therefore shall be selected for core diameter and numerical aperture to provide margin for initiating the explosive in the LID.

Testing of laser initiated ordnance systems and components shall use flight-like firing systems and fiber optic cables including all intermediate cable connectors.

5.3.5.6 Addressable Initiator System

Addressable initiator systems allow coded signals to be multiplexed over a common line or conductor path to one or more initiators either simultaneously or sequentially. Use of addressable initiator systems shall assure all safety, margin, reliability, and human engineering meet the intent of this standard for non-addressable initiation systems.

5.3.5.7 Mechanical

Mechanical initiation systems use mechanical kinetic energy to initiate explosive materials.

The system shall be failsafe by providing a mechanical inhibit that will not be removed until specified arming time. The inhibit will be designed to withstand all anticipated environments during handling, installation, and installed conditions. This type of system may require a mechanical interruptor in the explosive train.

5.3.6 Electro-Explosive System Protection

S&As shall be used in applications where unplanned release of ET output energy, or its chain of events, may cause injury or death to people or severely damage to property if required by customer specification or otherwise warranted. S&As shall also be used in applications where first element designs are susceptible to initiation from external energy environments, i.e., EMI, RF or ESD, if incident energy densities exceed accepted thresholds.

5.3.7 Transfer System

5.3.7.1 General

Explosive train systems transfer energy from the initiation system to the explosively actuated device. These systems shall be designed to ensure reliable initiation of the downstream element, and to reliably preclude initiation of the downstream element when an inhibit is required as part of the system.

5.3.7.2 Explosive Transfer Modes

End-to-end detonation transfer mode is preferred, but end-to-side and side-to-end modes may be used, in that order of preference. The side-to-side detonation transfer mode shall not be utilized.

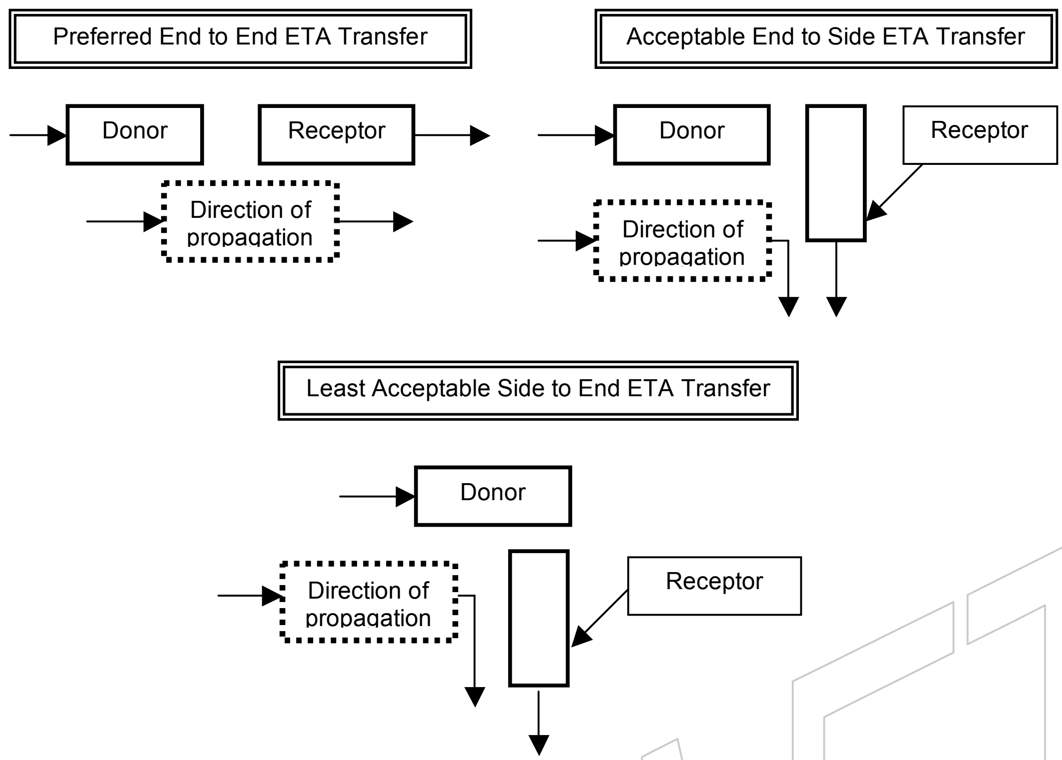

Figure 2 – Acceptable Explosive Transfer Modes

5.3.8 System Installation Design

5.3.8.1 General

Installation design must ensure explosive components systems do not need to be removed and replaced during normal maintenance.

5.3.8.2 Accessibility

System installation design shall provide for human access for installation of components into the vehicle and spacecraft.

Ensure all circuits are capable of being physically disconnected between the first element and its power supply as close to the first element as possible throughout all phases of ground operation.

First elements and associated circuitry shall be accessible to facilitate electrical checkout and final electrical connection as late as possible in the processing schedule.

Safe and arm visual indicators shall be always visible through an access in an assembled spacecraft and vehicle configuration.

Safing pins shall be capable of installation into and removal from a completely assembled spacecraft or vehicle.

Explosive systems shall be capable of being manually safed during any phase of ground operations.

If the S&A is to undergo a cycling verification test during any phase of ground operations, there shall be a capability to access and disconnect the explosive train from the S&A.

5.3.8.3 Flexible Transfer Line Installation

5.3.8.3.1 Free Length/Slack

Maximum length between tie points and allowable slack shall be established to prevent damage in dynamic environments. Design shall ensure the installation remains within established limits.

5.3.8.3.2 Shrinkage

The design length of flexible cords shall allow for shrinkage after firing to prevent loss of confinement or disconnection of end fittings.

5.3.9 Fragmentation and Fratricide

With exception of destruct systems, there shall be no deleterious fragmentation resulting from the operation of any device in the explosive train. Fratricide in which the operation of one system disrupts function of another system, or in which the operation of one leg of a redundant system disrupts function of the other leg shall not be allowed.

For unconfined detonating cords installation must ensure that functioning one cord does not damage any adjacent cords.

5.4 Component Design Requirement

5.4.1 General

All explosive devices shall be designed so as not to require any scheduled maintenance or repair during their service life. The designs shall accommodate easy installation, testing, or replacement at the user facility.

5.4.2 First Element Devices

5.4.2.1 General

First elements include low voltage EEDs, EBWs, EFIs, LIDs, and mechanical initiators.

The output of electrical first elements of the ET shall be configured to be compatible with the next element of the ET. Performance shall also not be degraded by exposure to dynamic and thermal environments anticipated before or during use in the end item application.

5.4.2.2 Bridge

The EED bridge element shall be capable of withstanding repeated measurements of its resistance values throughout its service life without degrading functional performance or safety.

For EED designs without discontinuities or gaps in their electrically conductive paths, the bridge shall be capable of withstanding repeated measurements of its resistance value throughout its service life without degrading functional performance or safety.

Carbon bridgewires are prohibited.

Conductive mix explosives shall not be used to replace the bridgewire.

5.4.2.3 Post-Fire Short Circuit Protection

As specified in Section 5.1, if the firing system is required to ensure an open EED firing circuit exists after EED firing, the EED must provide this post fire minimum open circuit resistance.

5.4.2.4 Shorting Devices / RF Protection

The design shall include a provision for shorting all contacts to each other. Once the initiator is assembled, adequate protection from RF, ESD, and handling damage shall be provided.

5.4.2.5 Booster Charges

Booster charges can be configured to be an integral part of the first element or be a separable assembly.

Electrically conductive explosive charges within EEDs and adjacent to the bridgewire shall be electrically isolated from the EED case.

5.4.2.6 All-Fire

5.4.2.6.1 Statistical All-Fire

Tests and analysis should determine the current, power, or energy level at which a design will reliably function. This should yield an input energy level, known as the statistical all-fire rating, at which, as a minimum, 99.9 % of the units from each design will function with a confidence of 95%.

5.4.2.6.2 Sure-Fire

Each device shall have specified an all-fire level that will provide reliable function of the device over the range of applicable temperatures, for all lots, and before and after environments. It also must ensure that the maximum function time requirement is conformed.

5.4.2.7 Low Voltage Electro-Explosive Device

All electrically conductive paths of the EED shall be isolated from the EED outer case. The insulation resistance between these conductors and the EED case shall be greater than 2 MΩ when a 250-VDC minimum potential is applied for 1 minute minimum.

All EEDs in a low voltage capacitive firing system shall fire when subjected to currents between sure-fire and 22 A.

The EED shall not fire when the bridgewire is subjected to the no-fire current. Unless otherwise specified, the minimum no-fire current shall be 1 A applied for at least 5 minutes. Firing probability when subjected to the no-fire current shall be less than 0.001 at 95% confidence level. Following exposure to this no-fire current, the EED shall be capable of performing within specified limits.

The EED shall not fire when the bridgewire is subjected to the no-fire power. Unless otherwise specified, the minimum no-fire power shall be a DC power of 1 W applied for at least 5 minutes. Firing probability when subjected to the no-fire power shall be less than 0.001 at 95% confidence level. Following exposure to this no-fire power, the EED shall be capable of performing within specified limits.

5.4.2.8 Semiconductor Bridge Device

SCBs shall meet the same requirements as low voltage, capacitor fired, EEDs. SCBs may be integrated into addressable, or intelligent, initiation systems. In this case each individual SCB contains electronics that allow the device to be fired upon receipt of a properly encoded arming/firing signal, and reject improperly coded signals.

5.4.2.9 High Voltage Electro-Explosive Device

These include EBW and EFI EED designs that require more than 500 VDC for initiation. They use high-energy electrical systems for initiation.

These devices shall not function or be degraded when subjected to a 500 VDC input from a 1.0 μF capacitor, applied for 1 minute, minimum, across input electrical conductors of the EED.

These devices shall not function or be degraded when subjected to 250 VAC applied across input electrical conductors for 5 minutes minimum.

The insulation resistance between pins and between pins and case shall be greater than 20 MΩ when 500 VDC is applied for 1 minute.

Gaps shall be independently hermetically sealed.

For EED designs with gaps, the condition of the bridgewire shall be evaluated by first determining acceptable limits of resonant frequency measurements of the EED electrical circuit design and then performing measurements on each EED produced. Alternatively, the continuity may be measured by supplying a high-voltage, limited duration current to break down the gap. The resistance can then be determined by measuring voltage and dividing that value by the current used.

For EED designs having interrupts or gaps in their electrically conductive paths, measurements of the amount of voltage required to arc across the gap shall be made as a means of the validating acceptability. The acceptable limits of this slow rise-rate breakdown voltage test are unique to each EED design and shall be determined during development.

5.4.2.10 Laser Initiated Device

LIDs shall have specific power density, spot size, pulse width, and wave length characteristics with a specified tolerance level for each characteristic.

LIDs contain an optical interface to allow passage of the laser energy from the firing system to the first fire explosive element. When containment of explosive combustion products is a requirement, the window shall withstand an internal pressure equal to four times its maximum internal peak operating pressure.

LID design shall ensure contact of the initiating explosive with the lens during and after exposure to all operating environments. Any change in manufacturing processes or materials shall require requalification of the LID.

LID design shall verify that installation torque does not degrade reliability.

LIDs may use pyrotechnic or secondary explosive as the initiating explosive consistent with the LID end application. Modification of explosives is permissible (e.g. adding carbon) if required to ensure reliable initiation, however their sensitivity characteristics shall be established in accordance with MIL-STD-1751.

Qualification of a LID solely by similarity and analysis is prohibited.

LIDs shall have an environmentally sealed protective cap installed on its input end at all times to maintain cleanliness of the window.

The all-fire and the 5-minute no-fire power shall be determined. The minimum all-fire power level shall be at least 10 times the no-fire level. If the LFU has built in test then the energy level shall not exceed 1/10,000 the no-fire energy measured at the LID.

5.4.2.11 Mechanical Device

Mechanical devices utilize springs that convert potential energy to kinetic energy to initiate a primer.

5.4.2.11.1 General

Percussion initiators shall be designed such that the all-fire energy does not exceed 50% of the minimum supplied operating energy. The no-fire energy shall be such that the percussion initiator shall not fire when subjected to an energy of 50% of the all-fire energy. These requirements apply over the operating temperature range.

5.4.2.11.2 Safing Mechanism

Each device of this type shall have an integral safing mechanism connected to a removable safing pin and 'REMOVE BEFORE FLIGHT' streamer. With the safing mechanism installed, the device shall be incapable of firing.

5.4.2.11.3 Primer All-Fire

The all-fire level of the primer shall be determined by statistical drop tests. Given a drop weight of W and statistical results of mean drop height and sigma, all fire level, AF, is defined as:

$$AF = 2 \times W(\bar{h} + 5\sigma)$$

where,

W = drop weight,

$\bar{h}$ = mean drop height,

σ = standard deviation.

5.4.2.11.4 Firing Pin Energy Margin

Minimum firing pin energy when considering worst case tolerances e.g. minimum firing pin stroke, minimum spring strength and rate, or maximum friction during pin travel, shall be greater than the all-fire energy.

5.4.2.11.5 Firing Mechanism

Pre-cocked firing mechanisms shall not be used.

5.4.3 Safe and Arm Device

5.4.3.1 General

S&As shall be used in applications where unplanned initiation of the explosive system may cause injury, death, or severe damage to property.

5.4.3.2 Electrically Actuated

This type device shall incorporate a means of remote electrical arming and disarming from any barrier position.

Remote and manual disarming shall be accomplished without passing through the arm position.

The device shall not be capable of being manually armed, but shall be capable of being manually disarmed.

The device shall remain mechanically secured in the selected position under all operational environments without the application of any electrical signal.

There shall be no current flow exceeding 2 mA in the disarm or safe command circuit during the arming cycle nor in the arm command circuit during disarm or safing.

The S&A shall have a demonstrated cyclic life of 1,000 safe-to-arm-to-safe transitions, or five times the number of transitions predicted during its lifetime, whichever is greater, without failure or degraded performance. The S&A barrier shall be capable of being manually positioned to “safe” during any phase of this cyclic life. This requirement shall be demonstrated during qualification tests. Post-test disassembly and inspection shall be used to confirm design adequacy.

5.4.3.2.1 Electrical Arming and Safing Time

The time required to arm or to safe the S&A, electrically actuated arm-disarm device, or other approved safing and controlling device shall not exceed 1 second after application of the actuation current.

5.4.3.2.2 Electrical Contacts

Electrical switching contacts shall be designed such that the specified vibration environment shall not cause an inadvertent make or break (chatter). Contacts that physically prevent closure (e.g. wiping type, disc-mounted) in the unarmed position are the preferred type of contact.

5.4.3.2.3 Safing

The S&A shall be safed by movement of a barrier between the EED and next explosive element to a position which inhibits detonation transfer, or misalign the EED and the next explosive element, and by disconnecting and shorting the firing electrical circuits as follows:

a) In the safe position, both power and return firing lines shall be disconnected.

b) In the safe position, the EEDs shall be shorted and the short should be grounded through an appropriate resistance. If the resistor(s) remain connected to the firing circuit in the arm position, it shall be a minimum of 10 KΩ.

c) Establishing and breaking circuit continuity, and shorting and un-shorting of the EEDs shall be accomplished by actuation of the device to align and dis-align the EEDs with the rest of the explosive system.

d) Transition of the barrier from the safe to the arm position for a rotating barrier shall require a minimum of 90° rotation of the barrier.

5.4.3.3 Mechanically Actuated

This type device shall incorporate the same features as electrically actuated devices except that arming and safing is performed mechanically. Normally these devices are armed by a lift-off lanyard or by stage separation. Electrically actuated devices shall be used unless justification for mechanical actuation is provided and approved by the procuring authority.

This device shall be designed to withstand repeated cycling from the armed to safe position for at least 300 cycles without malfunction, failure, or deterioration in performance.

5.4.3.4 Barrier Design

S&A designs shall include a physical barrier that, when positioned between the output of the first element and inputs to other downstream ET elements, inhibits explosive energy transfer. The ET shall be termed “safe” when the S&A barrier is positioned between these elements so that explosive energy transfer cannot occur. Likewise, it shall be termed “armed” when the barrier is positioned to allow explosive energy transfer. The barrier shall be designed to be manually or remotely driven to the “safe” position. This disarming operation shall be accomplished without passing through the “armed” position. The S&A design shall prevent manual positioning of the barrier to the “armed” position. The S&A barrier design shall provide a mechanical means to allow it to remain in “armed” or “safe” positions during all environmental conditions predicted by the application.

5.4.3.5 Barrier Performance

Tests or analyses or both shall be used to demonstrate that the S&A barrier will reliably inhibit explosive energy transfer between ET first and downstream elements. The demonstrations shall also evaluate limits of all possible barrier misalignments relative to “safe” and “armed” positions to establish performance margin limits for both inhibit reliability and energy transfer reliability.

5.4.3.6 Barrier Position Indicators

The S&A design shall provide remote and visible means to indicate the position of the barrier. Visual indicators shall be located within the S&A, although visible from the exterior. The visible indicator shall be readily discernible at least 15° from a line-of-sight normal of the centre of the indicator. It shall also be readable at a distance of 1.5 m away from the S&A. The visible indicators shall be highlighted using internationally recognized colors, red background with a black "A" for “armed” and green background with a white "S" for “safe.” The “safe” status indicator can be visible when the S&A barrier is within safe operation performance margin limits as determined by test or analysis. The “armed” indicator shall be visible when the S&A barrier position is within the region determined by tests and analysis to allow explosive energy transfer to the ET. The S&A user shall assume responsibility to ensure that indicators are visible when the S&A is installed in the application. Remote indicators shall also ensure that “safe” and “armed” status is within the performance margin limits determined by tests and analysis, and use the same criteria established for positioning of visual indicators.

5.4.3.7 Safing Pin

The S&A shall include a fail-safe mechanical device that inhibits remote arming of the S&A during application processing. The safing pin shall be manually removed from the S&A to allow arming.

Removal of the safing pin shall not cause the S&A barrier to transition to the “armed” position. The S&A design shall prevent safing pin removal when electrical circuits are commanded to position the S&A barrier to “armed.”

When installed, the safing pin shall prevent the S&A barrier from being positioned to “armed,” as established by tests and analysis. A feature such as a “remove-before-flight” streamer shall be attached to the safing pin to identify it as an item that needs to be removed before final use in the application.

It is the responsibility of the S&A user to ensure ready access in the application for safing pin removal and installation.

When the S&A is in the “safe” mode the safing pin shall be retained within it by design features that can survive environmental conditions predicted by the application. These design features shall apply resistance during safing pin removal and installation but not more than 45 N of tension or 1.1 N•m of torque. The design shall also prevent removal of the safing pin if the S&A is energized. This design shall provide resistance of at least 450 N of tension or 11 N•m of torque without failure.

A highly visible 'REMOVE BEFORE FLIGHT' streamer shall be attached to the safing pin.

Mechanical retention of the safing pin shall be possible only when the S&A is in the safe position.

5.4.3.8 Electrical Design

Electrical control, monitor, and EED circuitry shall be environmentally sealed within the S&A. Independent and isolated circuits and connectors shall be required for ET first element command and monitoring and for barrier command and monitoring. The S&A shall provide an enclosure for these circuits that shields them from external energy fields such as RF, EMI, and ESD, to the extent practical.

5.4.3.9 Stall

The S&A design shall be capable of meeting all performance requirements after application of maximum operational voltages for 5 minutes with safing pin installed. The S&A design shall also prevent degradation or premature initiation of any explosive component within the S&A if maximum operation voltages are applied to control circuits for 1 hour with the safing pin installed.

5.4.3.10 Switching Networks

Switching network designs using mechanical contacts for make-or-break circuits shall be validated by test that they will not inadvertently open or close during dynamic environments predicted during use in the application. During transition from S&A barrier safe to armed positions, each switching network contact shall completely disconnect prior to connecting to the next circuit.

5.4.3.11 Power Circuit Safety

When the S&A barrier is in the safe position, the switching network shall ensure power paths to all ET first elements are disconnected; this is to be established by test and analysis. Also, in the safe position as established, the paths to ET first elements shall be shorted through appropriate resistance to ground. If this ground path remains connected when the S&A barrier is in the "armed" position, the ground path resistance value shall be at least 10 kΩ.

5.4.3.12 Simulator Resistors

A S&A may use resistors installed across first element initiation circuits to allow for resistance or continuity measurements without applying energy to them. In safe, the application of operational voltages to these resistors for 20 seconds minimum shall not degrade subsequent S&A performance. The application of these voltages for a duration greater than 20 s shall not be cause for premature initiation of any explosive component within the S&A.

5.4.3.13 Rotor Leads

All lots of rotor leads shall be acceptance tested as a separate component. Rotor leads shall be qualified as an installed component in the S&A.

5.4.4 Linear Explosive Transmission

When additional elements downstream of the first element or S&A are required to effect transmission of the explosive energy to the explosively actuated device, these explosive elements shall be encased such that, when properly ignited, they allow linear energy transmission of detonation or deflagration waves.

These elements shall have fittings at each end to allow connection of them in the ET. The end fittings containing explosive charges shall accept inputs from the first element or S&A and either continue to propagate as detonations in the column or transition to deflagration.

Only explosive element designs having rigid metallic tubing installed over the explosive column with a demonstrated ability to contain combustion products shall be used in applications having contamination restrictions.

5.4.4.1 Interfaces

For applications where fragmentation of the fittings is not acceptable, tests and analysis shall show that structural integrity during and after the explosive transfer event is maintained.

Inert fittings shall be designed to correctly position and align the ETA end fittings to assure reliable explosive energy transfer to the next element in the ET.

5.4.4.2 Interrupters

Interrupters are similar to S&As except they do not contain integral EEDs. Interrupters are used to isolate primary explosives from down stream secondary explosives (e.g. LPI from a destruct charge or laser light output to a LID.) All applicable S&A requirements in this section shall be satisfied.

5.4.5 Explosive Delays

In specific applications where sequencing of explosive events is required, columns of linear explosive or pyrotechnics having slow burn rates or transfer speeds are used. The time delay design shall be capable of, but not restricted to, accepting a detonation input, then transition to deflagration, then back to detonation. Performance verification of time delays shall use the same methods used for energy transfer elements qualification and destructive acceptance, except that tests shall be performed with samples at predicted operating temperatures of the end item application in lieu of default temperatures in order to ensure that time delay duration is within required limits in the thermal environment in which it will be used.

Not all ordnance delays need either/both an explosive input and output. Some ordnance delays are mechanically initiated via a firing pin.

A key parameter in explosive time delay design is heat dissipation of the burning material. Inadequate compensation for the dissipation of heat generated in designs where the deflagration column is coiled onto a spool may be cause for initiation of adjacent coils or altered burn rates of the explosive material, or both.

5.4.6 Explosively Actuated Device

5.4.6.1 General

Explosively actuated devices are the final major element of an explosive system. They are components, mechanisms, or assemblies that use ET output energy to initiate and perform work in the end item application.

They may or may not contain explosive materials but may be designed to receive such a charge.

Performance margin verification methods for explosive-actuated devices are discussed in section 5.2. Tests deemed necessary for performance verification of unique or novel configurations shall be included in the series of demonstrations. Examples of explosive actuated devices commonly used in space vehicle systems include CAD; TBI; severance devices including LSC; penetrating devices including EFP, CSC and LSC; and fragmentary devices.

5.4.6.2 Cartridge Actuated Device

CADs shall be designed to contain all explosive gas products upon actuation.

CADs are explosively actuated devices that usually contain internally moving parts and which perform a mechanical function. CADs are usually actuated by the pressure output from one or more separable pressure cartridges; however CADs may contain an integral explosive charge. Pressure actuated separation nuts, separation bolts, pin-pullers, cutters, pyrovalves, and thrusters are examples of CADs.

All operational environments, mechanical loads, and the CADs associated interface and application shall be evaluated during design and verification of the CAD. Test set-ups, at both the component and system level, shall simulate the flight configuration to maximum extent practical. CADs shall be subjected to the margin test requirements of this specification where appropriate.

NSI and similarly configured initiators, shall not be used as the sole power source(s) for a CAD.

CAD performance shall not degrade due to potential pressure cartridge ejecta (e.g. closure disc, insulator materials, and unburned propellant) that might restrict gas-flow through internal passageways.

Internal pressures shall be measured during development and margin testing, and during qualification and lot testing. This information can then be used to establish performance limits for associated pressure cartridges. This is especially important if the pressure cartridges are manufactured and accepted separately from the CAD, or if the CAD and pressure cartridge are manufactured by separate organizations. Post-test radiographic inspection, disassembly, and dissection shall be used to assist evaluation of device performance.

5.4.6.2.1 Separation Nuts

Pressure actuated separation nuts, defined as those that use pressure from one or more explosive cartridges to actuate an internal mechanism to release a pre-segmented and assembled nut which in turn release the bolt or stud, and associated application, shall include the following provisions.

a) Re-settable separation nuts shall include a means of verifying that the nut is properly reset before and after its mating bolt or stud installation and torquing.

b) Unless a load-measuring device is used the relationship between bolt preload and torque shall be established and incorporated into the using system assembly procedures.

c) Separation nut applications shall preclude application of moments to the separation nut.

d) Separation nut design shall consider minimum and maximum bolts insertion lengths.

If separation nut or stud capture devices are used, they must be designed and tested to ensure that free components do not degrade any adjacent structure, system, or component.

Separation bolt design shall consider flight containment structure to ensure adequate bolt separation.

5.4.6.2.2 Separation Bolts

Separation bolts are devices that fracture at a specified position along their length to permit release and separation of two bodies. Separation bolts shall include the following provisions.

a) The bolt, and its application, shall consider worst case loading, dimensional tolerances and environments in its design. Spherical washers may be used where clamping faces may not be parallel or where in-flight rotation occurs.

b) If bolt capture devices are used they must be designed and tested to ensure that bolt halves do not degrade any adjacent structure, system or component.

c) Unless a load-measuring device is used the relationship between bolt preload and torque shall be established and incorporated into using system assembly procedures.

Separation bolt design shall consider flight containment structure to ensure adequate bolt separation.

5.4.6.2.3 Pullers

Pin pullers are explosively actuated devices with a pin that retracts upon actuation of one or more explosive cartridges.

The retractable pin shall have a mechanism that prevents rebound of the pin after its initial stroke.

Pin pullers shall be designed to accommodate loads in double shear. However, the pin puller also must accommodate any bending that might occur during pin retraction.

Sufficient stroke must be provided so that complete release is attained under worst-case dimensional tolerances and environmental conditions.

5.4.6.2.4 Thrusters

Thrusters are explosively actuated devices with a piston that extends upon actuation of one or more explosive cartridges.

Thrusters shall be designed to accommodate compressive loads as well as loads in double shear.

Sufficient stroke must be provided so that complete stroke is attained under worst-case dimensional tolerances and environmental conditions.

Thrusters shall be designed to retain the piston at the end of its travel.

5.4.6.2.5 Cutters

Cutters are explosively actuated devices that contain a blade and anvil. Upon initiation of one, or both explosive cartridges, the blade is driven towards the anvil severing any item in its path (e.g. electrical wires, braided textiles, steel cables, tubing, and bolts). Cutters shall include the following provisions:

The target material to be severed shall be defined in all specifications, test procedures, and installation procedures. Target drawings shall also specify that no changes be made that effect cutter performance.

Cutters shall be capable of severing a target having a cross sectional area at least 50% greater than the operational target. Cutters shall not fragment when fired with no target or when fired with all pressure cartridges loaded with 120% explosive charges.

Cutters shall be designed and testing shall consider all operational factors including loads, oblique cutting angles, and environments.

The cutting of electrical cables may cause prolonged contact between conductors and this characteristic must be conveyed to appropriate system designers and users.

Cutters with removable anvils shall have removable explosive cartridges.

5.4.6.2.6 Pyrovalves

Pyrovalves are used for fluid flow control, either normally closed that opens upon actuation or normally open that closes upon actuation. Pyrovalves consist of a body, a piston, and one or more separable pressure cartridges; upon actuation the piston either shears a bulkhead to open a valve, or plug an orifice to close a valve.

Combination pyrovalves consist of a single body and two or more valves. In this case special attention must be paid to ensuring pressure cartridges are not interchangeable.

If the fluid flow direction is critical then mating tube fittings must be differently configured. The pyrovalve piston must remain in its actuated position when subjected to a back pressure of at least twice the peak fluid operating pressure.

Pyrovalves shall be designed to isolate explosive gas products from any reactive fluid flow path or any flow path with contamination concerns.

5.4.6.2.7 Shaped Charge

Charge holders shall be used for all shaped charge functions to ensure proper charge orientation and standoff. Charge holders and other attachment fittings to position shaped charges shall be designed to survive the same environmental exposures as the devices themselves.

SCAs shall be designed to accommodate any change in structural dimensions due to thermal expansion/contraction or expansion due to flight conditions.

5.5 Operations and Maintenance

5.5.1 Age Surveillance of Explosive Components

5.5.1.1 General

Although the specific component design may have satisfied all material compatibility tests and analysis, subtle lot-to-lot manufacturing and processing variations may have adverse effects on a particular production lot of the design. Potential adverse effects can only be determined by inspections of samples from each production lot. These inspections are destructive; therefore, they cannot be performed on items to be used in the end item application. The solution is to perform a periodic age surveillance test of samples from each production lot. Surveillance tests can then be used as tools to detect potential anomalous conditions before other items from the lot are used in the end item application.

5.5.1.2 Age Surveillance

Age Surveillance Tests are performed to extend the service life of the component lot by 1 year.

Testing should be performed in a timely manner to support end use but allow schedule recovery should an anomaly occur.

The tests can be repeated at time intervals determined to best fit end item application needs.

There is no limit to the number of tests performed on any specific production lot of components.

5.5.1.3 Accelerated Age Surveillance

Accelerated Age Surveillance Tests are performed to extend the service life of the component by 3 years or more.

This test exposes the components to 71°C for thirty days. Testing assumes a linear relationship between test duration and life extension. Longer test durations may be used to provide life extension beyond 3 years.

If the component to be tested is in any way damaged by exposure to 71°C, lower temperatures may be used according to the following Arrhenius equation:

$$k = A \times \exp\left(\frac{-E_a}{R \times T}\right)$$

where,

k = the rate coefficient,

A = Arrhenius rate constant,

E_a = the activation energy,

R = the universal gas constant (8.314×10^{-3} KJ mol^{-1} K^{-1}), and

T = the temperature (in degrees Kelvin).

Testing should be performed in a timely manner to support end use but allow schedule recovery should an anomaly occur.

The tests can be repeated at time intervals determined to best fit end item application needs.

There is no limit to the number of tests performed on any specific production lot of components.

5.5.2 Packaging, Handling, Storage and Transportation

Explosive devices and systems shall be packaged, labeled, marked, placarded, and shipped in accordance with the applicable requirements of Code of Federal Regulations, Title 49. Identification of 24 hour per day/7 day per week point of contact for emergencies shall be provided.

Explosive devices shall be packaged, handled, stored and transported in a manner that assures safety, form, fit, function, interface and service life are not adversely affected. Sealed packages using approved, nonvolatile materials shall be used.

Extreme storage, packaging, handling and transportation environments shall either be included in qualification and acceptance testing or controlled to within the maximum predicted levels used to determine qualifications requirements. Adverse storage, transportation, and handling environments exceeding these established limits shall be identified and evaluated on a case-by-case basis. Records of storage conditions shall be maintained. Cleanliness and protection shall be maintained during processing, storage, and transportation.

Technical descriptions clearly stating potential hazards and identifying methods for prevention of hazardous conditions when handling the explosive system and components shall be available to transportation, handling and storage personnel.

All EEDs and S&As shall have shielding caps installed during all packaging, handling, storage and transportation.

5.5.3 Installation and Operating Procedures

Installation and operating procedures shall be established for all systems and devices. These procedures shall be compatible with safety requirements and personnel control requirements at the facility where the operations are conducted.

All EEDs and S&As shall have shielding caps installed during all installation operations.

6 Verification Requirements

6.1 General

This section presents verification requirements for explosive systems and devices to determine their acceptability before use.

Each requirement of Section 5 must be validated by inspection, test, demonstration, or analysis. The supplier shall prepare a table identifying how each requirement is to be verified.

Test programs and specific tests described herein are the minimum to be used to verify components and systems. For a particular program, additional tests such as salt fog, sand and dust, temperature, humidity, altitude, thermal shock, transportation vibration/shock, acceleration, space simulation, propellant compatibility, radiation, fungus, etc. may be applicable. Each program shall determine applicable environments as described in paragraph 5.1.1 and specify how the system/component survivability shall be verified. Test methods for these additional tests may be found in other documents such as MIL-STD-810F(3).

6.1.1 Responsibility for Verification

Unless otherwise specified in the contract, the supplier is responsible for verifying their devices or systems meet the requirements of Section 5. Verification may be accomplished by inspection, analysis, demonstration, or test.

Unless otherwise specified in the contract, the supplier is responsible for and shall use his own facilities or other suitable facilities for performance of all inspections, tests, and analyses specified herein. The supplier shall ensure that facilities have adequate equipment and quality provisions for performance of the required tests or inspections.

6.1.2 Verification Process

Component and system verification consists of:

a) parts, materials, and process controls,

b) threshold / margin,

c) qualification,

d) acceptance, and

e) service life extension.

6.1.2.1 Parts, Materials and Process Controls

All parts, materials, processes, inspections and tests applicable to manufacture of the device or system shall be specified, documented, and controlled to an approved baseline as specified in Sections 5.1.8 and 5.1.16. During production, the parts, materials, processes, tooling and equipment shall be controlled and inspected to ensure compliance with the approved baseline. Complete records shall be documented and maintained to fully define all aspects of each assembled unit or system.

6.1.2.2 Threshold / Margin

Tests shall be performed to verify compliance with margin requirements of Section 5.2 for each interface in the system. This is especially important if, for example, pressure cartridges are manufactured and accepted separately from the using CAD, or if the CAD and pressure cartridge are manufactured by separate organizations. Post-test radiographic inspection, disassembly, and dissection shall be used to assist evaluation of device performance.

These tests may be performed in conjunction with development or qualification programs or may be a stand-alone program. Margin tests shall be repeated if the design changes to the point of invalidating the margin results. Test units to be used during these tests shall be sufficiently similar to the baseline to be used in qualification to ensure margin results remain applicable. Alternate test methods to those indicated herein may be utilized if approved by the procuring authority.

These tests are described in Section 6.2.

6.1.2.3 Qualification

Tests shall be performed to demonstrate the design of the device or system meet the specified requirements. Environmental test levels and durations specified herein shall be established to provide margin over actual flight levels and durations.

Qualification test matrices are included in Tables A.4–A.6.

6.1.2.3.1 Qualification Configuration

All qualification tests shall be performed with devices / systems of the final design that have been manufactured in accordance with the approved parts, materials, and processes, and in-process inspections and tests.

Qualification testing shall be performed for each device and for higher levels of system assembly, e.g. an EED, which is to be used in a CAD, shall be subjected to the EED qualification program, and the CAD with EED installed shall be subjected to the Other Device qualification program. When a device and its EED both require qualification testing, the test programs may be combined provided the total test program satisfies all requirements for EED qualification and all requirements for the device qualification.

6.1.2.3.2 Qualification by Similarity

It may be possible to verify that existing designs previously qualified for other applications have adequately demonstrated compliance with all or part of the qualification requirements for the current application. In this case, all or part of qualification may be accomplished by similarity to the previous (reference) device or system. Limitations to the use of qualification by similarity are indicated below.

a) Qualification by similarity shall not be accomplished by using similarity to another device or system that was also qualified by similarity.

b) Qualification by similarity shall not be accomplished against a device manufactured by a different manufacturer or at a different manufacturer location.

c) Qualification by similarity shall verify that the reference device or system testing was performed in a manner that satisfies the Test As You Fly requirement of paragraph 6.1.6 for the current application.

d) Any changes in design or manufacturing processing between the current device or system and the reference device or system shall be identified and assessed as to impact on use of qualification by similarity.

e) Full or partial qualification by similarity shall be approved by the procuring authority prior to delivery of any hardware.

6.1.2.3.3 Re-qualification

A device or system shall be re-qualified if there is a change in:

— design,

— environmental levels to which it will be exposed,

— manufacturer or manufacturer location,

— parts, materials, and processes, or

— energetic material or energetic material manufacturer.

6.1.2.3.4 Delta Qualification

A reduced scope qualification program may be used to:

— supplement missing data in the qualification by similarity assessment above;

— re-qualify a device or system for increased environmental levels; or,

— re-qualify a device or system that has undergone changes in design or manufacturing parts, materials, or processes that have been determined to negatively impact the qualification status.

The scope of the delta qualification program shall be reviewed and approved by the procuring authority.

6.1.2.4 Acceptance

Acceptance testing shall be performed on each production lot and, along with acceptable manufacturing records as described in paragraph 6.1.2.1, shall be the basis for lot acceptance. Acceptance testing shall consist of Non-Destructive and Destructive Acceptance Tests.

Each production lot will be granted an initial service life depending on the device type and type of testing performed during Destructive Acceptance Tests. This initial service life shall begin at completion of Destructive Acceptance Tests.

6.1.2.4.1 Non-Destructive Acceptance

Each unit in the production lot shall be subjected to the NDTs. Failure of an individual unit to pass one of these tests shall be cause for rejection of that unit. Excessive reject rates that occur during this phase of testing shall be handled in accordance with paragraph 6.1.7.

Non-Destructive acceptance test matrices are included in Tables A.1–A.3.

6.1.2.4.2 Destructive Acceptance

Upon completion of NDT, a sample of the production lot shall be randomly selected and subjected to Destructive Acceptance Testing. Quantities as described in Tables A.7 and A.8 to be used in this test may be reduced if statistics based on measured data for key performance parameters are significantly better than the specified limits per established statistical analysis as described AIAA-2005-4039.

Unit serial numbers selected for this testing:

a) may not be pre-selected or pre-identified during the manufacturing process;

b) must be spread throughout the lot, i.e. representative of the entire lot; and,

c) must represent all sub-groups in the lot as defined in paragraph 5.1.16.3.

Destructive Acceptance test matrices are included in Tables A.7–A.8.

6.1.2.5 Service Life Extension

Service life for a lot may be extended by performance of either of two types of Service Life Extension Tests and/or by Trend Life Analysis as described AIAA-2005-4039. Service life for the lot may be allowed to expire and the expired devices retained in storage until life extension is required. Units to be used in the life extension testing shall have been stored with remaining units in the lot or in an environment that simulates storage conditions for remaining units in the lot.

The new life will begin at completion of life extension tests.

Service life extension test matrices are included in Tables A.9–A.10.

6.1.2.5.1 Age Surveillance

Performance of this type of testing extends the life of the device by one year. Paragraph 5.5.1 provides additional definition for this test.

6.1.2.5.2 Accelerated Aging

Performance of this type of testing typically extends the life of the device by three years or more.

a) This test exposes the components to 71°C for thirty days as described in Method 209. Testing assumes a linear relationship between test duration and life extension. Longer test durations may be used to provide life extension beyond three years.

b) If the component to be tested is in any way damaged by exposure to 71°C lower temperatures may be used according to the following equation:

$$H_L = H_T \times 3^{\frac{(T_1 - T_2)}{11.1}}$$

where:

H_L = service life (in hours),

H_T = test time duration (in hours),

T_1 = test temperature (in °C),

T_2 = in-service storage temperature (in °C),

3.0 = reaction rate factor.

6.1.3 Applicable Documentation

For all tests and inspections, applicable documents include product specifications and engineering drawings, documents, etc. which describe product design details and define the detailed requirements for performance of the specific inspection or test and applicable success criteria. Where specific requirements documents such as ISO, military, or industrial standards and specifications are applicable to a section of the document for a specific test or inspection, these will be identified in that section. When multiple standards and specifications are listed in a section, the manufacturer may select the document(s) to be used for the particular product.

6.1.4 Equipment Accuracy

Equipment used for all tests and inspections shall have an acceptance measurement tolerance to equipment accuracy ratio of 5:1 or better whenever possible. If the appropriate measuring instrument is unavailable for maintaining the ratio of 5:1, a ratio as low as 2:1 may be used provided the known or allowed measurement uncertainty is subtracted from both the high and low ends of the measurement tolerance. This new range shall be considered the acceptance tolerance. The contractor shall identify all equipment which cannot meet the 5:1 ratio.

If, due to state of the art limitations, the available measuring instrument is incapable of indicating the required number of decimal places, the recorded value shall be that which can be accurately determined by the instrument or the product specification shall call out accuracy which is not beyond the state of the art.

6.1.5 Equipment Sampling Rate

Sampling rate shall be adequate for the test parameter being measured. In the event that high sampling rate is utilized the time average of the parameter being measured shall be considered for success criteria.

6.1.6 Test As You Fly

Test definitions as well as fixtures to be used for testing of devices or systems shall be designed to simulate the intended flight applications to the greatest extend possible. All aspects of applicable flight and environmental conditions and parameters shall be considered when defining the test program and fixtures applicable to the device or system. Any variation from flight like conditions shall be evaluated for its impact to acceptability of test results being extrapolated to flight conditions. This evaluation and its conclusions shall be approved by the procuring authority.

The following example test definitions are not all-inclusive.

a) Test shall use flight like interfaces including loads, masses, standoff, confinement, alignment of components, materials, etc.

b) Functional testing of devices that interface with reactive fluids, e.g. fuel and oxidizer, shall be performed with the reference fluids.

c) Vibration and shock testing set-up shall include matting electrical harnesses and ETA lines to the first tie down. All electrical circuits shall be continuously monitored.

d) Test shall use flight operating input conditions such as current, voltage, etc. Functional testing of capacitive discharge systems shall use the same design capacitor and switch and impedance values as used in the flight fire set.

e) Functional testing shall use flight like interfacing explosive components and interfaces.

6.1.7 Test Tolerances

The tolerances shown in Table 1 shall be applicable to all testing.

Table 1 — Test Tolerances

Temperature	±3 °C
Pressure	
Above 1.3 x 10^{2} Pa	±10%
1.3 x 10^{-1} to 1.3 x 10^{2} Pa	±25%
Less than 1.3 x 10^{-1} Pa	±80%
Relative Humidity	±5%
Vibration Frequency	±2%
Random Vibration Power Spectral Density (G^2/Hz)	
20 to 100 Hz (5 Hz or narrower bands)	±1.5 dB
100 to 500 Hz (25 Hz or narrower bands)	±1.5 dB
500 to 2000 Hz (50 Hz or narrower bands)	±1.5 dB
Overall GRMS	±0.75 dB
Shock Response Spectrum (Q = 10)	
1/6 Octave Band Center Frequency Amplitude	+6 dB/-3dB
Static Load	±5%

6.1.8 Excessive Reject Rates

For each non-destructive test and inspection, reject rates which exceed 20% of the total number of items in a production lot shall require investigation into cause, effect, and corrective action. For each lot which incurs a cumulative reject rate of greater than 35% an investigation into cause, effect, and corrective action shall also be conducted. These investigations shall be fully coordinated with the customer before proceeding with the lot.

6.1.9 Test Procedure

A detailed test procedure shall be prepared for each test program to be performed on the system or device. This procedure shall, as a minimum, define items to be tested, tests to be performed, quantities to be tested, test set up, test equipment to be used and associated accuracy, safety precautions, environmental conditions and limits, acceptance criteria, and data sheet for recording of data.

6.1.10 Test Report

Upon completion of each test program, a report that contains all information and data pertinent to the test program shall be generated and submitted. Examples of information and data include:

a) part numbers, lot numbers, and serial numbers tested,

b) description of tests performed and all data related to the tests,

c) identification of all test anomalies or failures and final disposition.

6.1.11 Test Failure / Retest

Failure of a device or system to meet requirements of any tests with the exception of Non-Destructive Acceptance Tests prior to commencement of destructive testing shall be referred to as a lot test failure. The following conditions shall constitute a test failure:

a) any unit which does not satisfy a performance requirement;

b) any component sample that exhibits any sign that a part is stressed beyond its design limit, such as cracked circuit board, bent clamps, worn part, or loose connector screw, even if the component passes the final functional test;

c) any discontinuity or dropout in a measured performance parameter that could prevent the component from satisfying a performance requirement;

d) any inadvertent output.

In the event of test failure, the test setup shall be frozen although power may be removed from the setup. If the failure can be verified to be any cause external to the unit under test, e.g. test equipment, test setup etc., and the unit under test was not in any way damaged by the failed test, the unit may be retested. Retest of the device or system must be coordinated with and approved by the procuring authority.

Test failures shall be reported to the procuring authority within 24 hours. A written failure notification must be delivered to the procuring authority within 72 hours.

6.1.12 Failure Analysis

In the event of a test failure, a failure analysis shall be performed, documented and coordinated with the procuring authority. The failure analysis shall identify cause of failure, mechanism of the failure, and isolate the failure to the smallest replaceable item or items and ensure that there are no generic design, workmanship, or process problems with other flight components of similar configuration.

This requirement includes failure of tests conducted at the supplier facility, contractor facility, or launch site.

A formal report containing description of the failure, analysis of the failure and corrective actions, if required, shall be prepared and submitted to the procuring authority. Implementation of corrective actions and resumption of testing shall not commence until approved by the procuring authority. The failure report shall be approved prior to launch.

6.2 Margin Verification

6.2.1 General

Test fixtures used shall be configured to simulate the application including mechanical, dynamic and structural stiffness, to the extent practical. Interfaces between the device and the application that induce loads or friction, temperature, or other conditions on the device shall also be simulated, to the extent practical.

It is permissible to combine tests to reduce total test quantity provided individual test requirements are not compromised.

6.2.2 Statistical All-fire

The initiation threshold level (statistical all-fire) shall be established for each first element. This level shall provide initiation satisfying reliability requirements defined herein. Statistical methods that may be used to establish threshold level include but are not limited to Bruceton, Langlie, and Neyer.

Devices used in these demonstrations shall be configured to be identical to those planned for use in the end item application. These test methods are described in the appendices.

6.2.2.1 EED, EFI, SCB, HVD, LID

For devices such as these, a statistical test such as that described in Test Method 211 is typically employed to determine the pertinent parameter all-fire threshold level for a reliability of 99.9% at 95% confidence level. As mentioned in paragraph 5.4.2.6.1, this is referred to as the statistical all-fire. The program shall identify if a parametric study is needed at this point to characterize all-fire against various first-fire mix particle sizes, densities, coloring, etc. A parametric study such as this would ensure that allowed variances in manufacturing processes would not impact margin.

6.2.2.2 Mechanical Initiator

For a primer initiated device, the all-fire level is determined for each lot of primers manufactured by a drop test in which a known weight, W, is dropped from various heights onto a firing pin which rests on the primer under test. Height is varied according to the statistical test being performed. After mean drop height, H, and standard deviation, sigma, have been determined, the all-fire level is defined as W X (H + 5 sigma).

6.2.3 Initiation System to First Element

The initiation system shall be assessed by test or analysis to determine its worst-case low output. This output shall be compared with the threshold level of the device being fired and the margin between the two shall comply with the requirements of Section 5.2.

6.2.4 Booster Charges

Integral designs can be certified for use in the application using first element tests.

Booster charge designs that are not integral with the first element shall use tests for explosive energy transfer.

The ability for the donor charge/device to properly initiate the booster charge shall be validated by using 10 donors loaded to 80% of minimum specified charge weight or 80% of the worst-case donor minimum energy, whichever is less, mated to the booster charge in a flight like condition. Half of the units shall be fired at the design MPE upper temperature limit and the other half at the design MPE lower temperature limit. Satisfactory margin is demonstrated if all tests are successful.

6.2.5 Detonation Transfer

6.2.5.1 Across Air Gaps

Transfer across air between ETA end tips is typically performed at gaps less than 0.250 inch. If a design incorporates gaps greater than this, the initiating shock pressure at the receptor charge may be near the threshold. If that is the case, then variations in temperature, alignment, donor explosive lot, or receptor explosive lot may significantly impact margin, and even result in transfer failures. Designs with large gaps shall determine if some type of margin verification is necessary for each production lot of explosives.

A total of 10 tests shall be performed to account for variations in angular and axial offset between donor and acceptor charges. The maximum design stackup of angular and axial offset (including detonating cord end tip maximum allowable angular offset to the axis of the ferrule) shall be determined and margin shall be established by firing nominal donor and receptor charges at 4 times angular offset (5 tests) and 4 times axial offset (5 tests) at maximum allowable design gap. Testing may combine axial offset and angular offset or these margin conditions may be performed independently. Satisfactory margin is established if all tests are successful.

Tests shall also be performed to verify margin across the air gap. One of the following methods may be used.

6.2.5.1.1 Increased / Decreased Gap Method

A total of 10 tests shall be performed, 5 at no greater than 50% of the minimum design gap and 5 at no less than 0.250 inch or maximum design gap plus 4 times the variation between nominal design gap and maximum design gap, whichever is greater. This test method shall be performed by using nominal donor and receptor charges. Satisfactory margin is demonstrated if all receptor charges are successfully detonated.

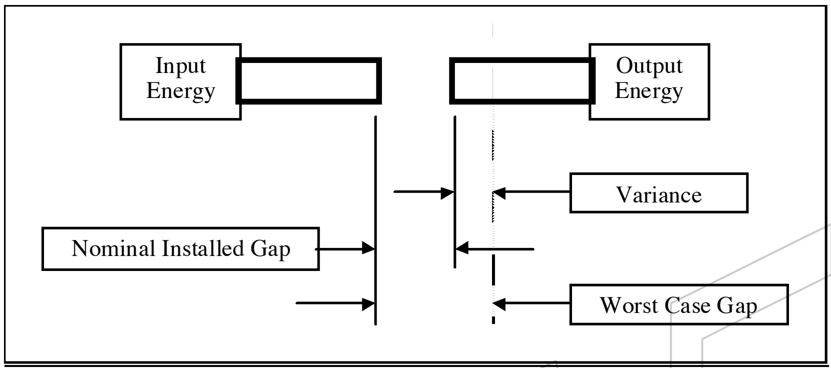

Figure 3 — Gap Margin Test Methodology Definition

6.2.5.1.2 Reduced Donor Charge

A total of 10 tests shall be performed using donor charges which are 75% or less of the minimum specified charge with nominal receptor charges. Half of these tests shall be performed using the minimum specified air gap and half performed using the maximum specified air gap. Satisfactory margin is demonstrated if all receptor charges are successfully detonated.

6.2.5.1.3 Flyer Shock Pressure vs. Receptor Threshold Method

Detonation transfer margin may also be established by determining donor flyer shock pressure time profile when it hits the receptor and compare it with threshold parameters for the receptor. This method requires measurement of flyer velocity as may be determined by VISAR or flash x-ray testing, and threshold initiation level of the receptor charge. A margin of 2 or more shall be considered acceptable.

6.2.5.2 Across Air Gaps with Intermediate Barrier

When a barrier exists in the path between donor and acceptor as shown below, transfer testing shall be performed. A total of 10 test firings shall be performed using nominal donor and acceptor charges as defined below.

a) 5 tests with gap between donor charge and barrier increased to no less than 0.250 inch or maximum design gap plus 4 times the variation between nominal design gap and maximum design gap, whichever is greater and nominal gap between barrier and acceptor charge. Satisfactory margin is demonstrated if all receptor charges are successfully detonated.

b) 5 tests with nominal gap between donor charge and barrier and gap between barrier and acceptor charge increased to no less than 0.250 inch or maximum design gap plus 4 times the variation between nominal design gap and maximum design gap, whichever is greater. Satisfactory margin is demonstrated if all receptor charges are successfully detonated.

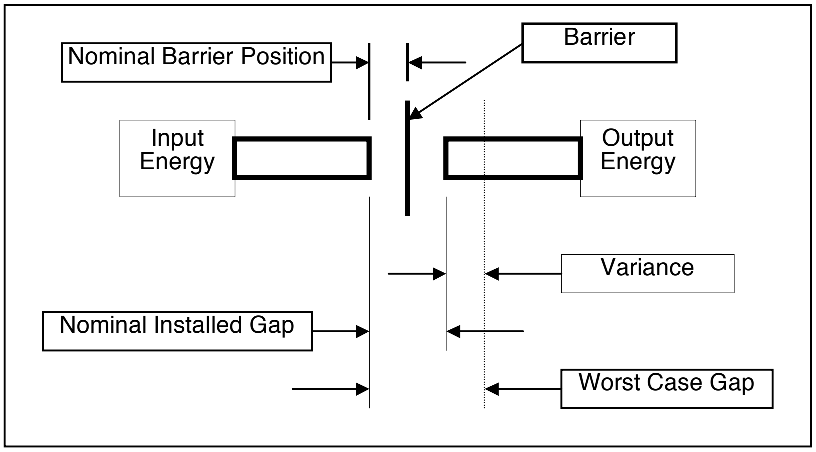

Figure 4 — Barrier Gap Margin Test Methodology Definition

6.2.5.3 Through Bulkheads

Designs with integral bulkheads shall have margin established both for detonation transfer and for bulkhead integrity as described below.

a) A total of 6 tests shall be performed to verify detonation transfer. These tests shall be performed with the bulkhead thickness increased to 1.2 times maximum design thickness. Half of the units shall be fired at the design MPE upper temperature limit and the other half at the design MPE lower temperature limit. Satisfactory margin is demonstrated if performance requirements are satisfied for all tests.

b) A total of 6 tests shall be performed to verify bulkhead integrity. These tests shall be performed with the bulkhead thickness decreased to 0.8 times minimum design thickness. Half of the units shall be fired at the design MPE upper temperature limit and the other half at the design MPE lower temperature limit. Satisfactory margin is demonstrated if the requirements of paragraph 5.2.4.3 are satisfied.

6.2.6 End Item Devices

6.2.7 Cartridge Actuated Device

The following margin tests of CADs shall be performed to verify charge weight and mechanical load conditions.

6.2.7.1 Minimum Charge Output

A total of 5 units shall be tested with cartridges loaded to 80% of minimum specified charge weight or 80% of the worst-case cartridge minimum energy, whichever is less, and with maximum predicted operating load as follows:

a) 2 units shall be fired at the design MPE upper temperature limit, and

b) 3 units shall be fired at the design MPE lower temperature limit.

If the CAD design incorporates redundant cartridges, tests shall be performed with only one cartridge firing. For these tests, CAD performance shall meet nominal specified performance requirements. Satisfactory margin is demonstrated if all tests are successful.

6.2.7.2 Maximum Charge Output

A total of 5 units shall be tested with cartridges loaded to 120% of maximum specified charge weight or 120% of the worst-case cartridge maximum energy, whichever is greater, and with minimum predicted operating load as follows:

a) 3 units shall be fired at the design MPE upper temperature limit, and

b) 2 units shall be fired at the design MPE lower temperature limit.

If the CAD design incorporates redundant cartridges, tests shall be performed with both cartridges firing simultaneously. For these tests, CAD performance shall meet nominal specified performance requirements. Satisfactory margin is demonstrated if all tests are successful.

6.2.7.3 Mechanical Load

A total of 5 units shall be tested with nominal cartridge loads and with the mechanical load increased to 150% of maximum specified operating load as follows:

a) 3 units shall be fired at the design MPE upper temperature limit, and

b) 2 units shall be fired at the design MPE lower temperature limit.

If the CAD design incorporates redundant cartridges, tests shall be performed with both cartridges firing simultaneously. For these tests, CAD performance shall meet nominal specified performance requirements. Satisfactory margin is demonstrated if all tests are successful.

6.2.7.4 No Load

A total of 5 units shall be tested with nominal cartridge loads and with the mechanical load decreased to 0 as follows:

a) 2 units shall be fired at the design MPE upper temperature limit, and

b) 3 units shall be fired at the design MPE lower temperature limit.

If the CAD design incorporates redundant cartridges, tests shall be performed with both cartridges firing simultaneously. For these tests, the CAD shall not fail structurally. Satisfactory margin is demonstrated if all tests are successful.

6.2.7.5 Locked Shut

If it is possible for the CAD to be exposed to a condition in which it will not be allowed to actuate when cartridges are fired this test shall be performed. A total of 2 units shall be tested with cartridges loaded to 120% of maximum specified charge weight or 120% of the worst-case cartridge maximum energy, whichever is greater, and with the actuating mechanism(s) restrained so it will not move as follows:

a) 1 unit shall be fired at the design MPE upper temperature limit, and

b) 1 unit shall be fired at the design MPE lower temperature limit.

If the CAD design incorporates redundant cartridges, tests shall be performed with both cartridges firing simultaneously. For these tests, the CAD shall not rupture or emit gases or shrapnel that could be hazardous to personnel or adjacent systems. Satisfactory margin is demonstrated if all tests are successful.

6.2.8 Severing and Penetrating Devices

Margin for severing and penetrating explosive charges shall be established by performance of one of the following tests.

a) Homogeneous Material Target: A minimum of 5 nominal charges positioned at maximum specified standoff shall be fired at nominal operating temperature against a target, which is flight like except its thickness is 150% of maximum specified thickness. Satisfactory margin is demonstrated if target penetration, severance, or break meets performance requirements.

b) Multiple Composite Substrate Target: A minimum of 5 nominal charges positioned at maximum specified standoff shall be fired at nominal operating temperature against a target, which is flight like except its thickness is 200% of maximum specified thickness. Substrate materials shall be identical to those to be used in flight. Satisfactory margin is demonstrated if target penetration, severance, or break meets performance requirements.

6.2.9 Expanding Tube Separation Systems

A minimum of five nominal charges shall be fired at nominal operating temperature, which is flight like except the thickness of the structure to be separated is 120% of maximum specified thickness. Satisfactory margin is demonstrated if severance meets performance requirements, including maintenance of tube integrity and containment of all detonation products.

6.2.10 Fracturing Devices

Margin for these devices shall be verified by 80% and 120% charges as specified in paragraphs 5.2.7. If it is impractical to vary explosive charge weight, the following tests shall be performed:

A total of 6 units shall be tested with nominal specified charge weight used to fracture a device with a break area that is 120% of the maximum specified design break area with no applied operating load as follows:

a) 3 units shall be fired at the design MPE upper temperature limit, and

b) 3 units shall be fired at the design MPE lower temperature limit.

Satisfactory margin is demonstrated if all fractures meet specified performance requirements.

6.2.11 Flight Vehicle Protective Covers for Devices Producing Fragmentation

A total of 2 flight like covers with thickness equal to or less than 80% of minimum specified thickness shall be tested using flight like explosive as follows:

a) 1 unit shall be fired at the design MPE upper temperature limit, and

b) 1 unit shall be fired at the design MPE lower temperature limit.

If the explosive device has two explosive charges, both charges shall be fired simultaneously. Satisfactory margin is demonstrated if the covers do not fail to contain all fragmentation.

6.2.12 Linear Thrusting Joints

The following margin tests of linear thrusting joints shall be performed to verify charge weight.

6.2.12.1 Minimum Charge Weight

A total of 5 units shall be tested with cartridges loaded to 80% of minimum specified charge weight and nominal joint design as follows:

a) 2 units shall be fired at the design MPE upper temperature limit, and

b) 3 units shall be fired at the design MPE lower temperature limit.

If the joint design incorporates redundant detonators, tests shall be performed with only one detonator fired. For these tests, performance shall meet nominal specified performance requirements. Satisfactory margin is demonstrated if all tests are successful.

6.2.12.2 Maximum Charge Weight

A total of 5 units shall be tested with cartridges loaded to 120% of maximum specified charge weight and nominal joint design as follows:

a) 3 units shall be fired at the design MPE upper temperature limit, and

b) 2 units shall be fired at the design MPE lower temperature limit.

If the joint design incorporates redundant detonators, tests shall be performed with both detonators fired simultaneously. For these tests, performance shall meet nominal specified performance requirements. Satisfactory margin is demonstrated if all tests are successful.

6.3 Functional Test Requirements

6.3.1 Testing at Temperature

When test firings are to be performed at temperatures other than ambient, the units being tested shall be conditioned and fired in the thermal conditioning chamber to ensure the unit being tested is in fact tested at the specified temperature. If this is not possible, the test setup shall ensure the device is at specified temperature at the time of firing.

6.3.2 Post Fire Visual Examination

After completion of functional test, visually examine the test unit for unacceptable damage.

6.3.3 Testing of Devices with Redundant Inputs

For designs using redundant inputs, tests to be performed at cold temperatures shall be fired with a single input. Tests performed at high temperature shall be performed with both inputs.

6.3.4 Closed Bomb Testing

Closed bombs may be used to characterize and validate the performance of devices that produce pressure. In general, the following requirements for use of these devices shall apply.

a) At the beginning of the program, during development of the device that is to be functioned by the EED, performance of the EED in the device and in each closed bomb shall be characterized and from this, reasonable bomb firing pressure/time requirements shall be established. These requirements shall bracket maximum and minimum acceptable EED performance in a manner that would reject EEDs that would produce unacceptable device performance.

b) The closed bomb shall have redundant instrumentation.

c) The bomb shall be designed to provide the same internal volume for repeated test firings. Internal design shall provide as simple a volume as practical. Bombs with multiple or complex shaped internal volumes shall not be used.

d) Consideration shall be given to design of the cleanout plug and its seal to minimize exposure of its threads to the hot gas from cartridge firing.

e) Each closed bomb shall be calibrated and serialized. The serial number shall be identified on the test data sheet.

6.3.5 Energy Sensor Tool

Energy sensors are used to measure and characterize the kinetic energy output of ordnance devices. Types of energy sensors include the crush type and the mass-velocity type. The former generally uses a crushable or deformable material with calibration curves. The energy output is proportional to crush depth. The mass-velocity type of energy sensor consists of a mass ejected from a tube and energy as a function of the ejected mass velocity.

6.3.6 Dent Test

Dent testing may be used to characterize and validate the performance of devices that produce a detonation output. The following dent test requirements are provided as a guide and are not necessarily all-inclusive.

a) Detonating devices may be tested using a metal witness plate, i.e. dent block, to record output through a dent depth measurement technique. The dent block shall be controlled as to material, material hardness, finish, thickness, and flatness. Control of hardness shall ensure variations in this parameter do not adversely influence dent depth from a detonator firing. Hardness of each dent block shall be recorded on the test data record.

b) The test setup shall hold the unit under test against the dent block in such a manner that no unacceptable gaps between the two exist. Care shall be taken to ensure the flyer does not embed itself in the dent block. A thin coat of lubricant between the test unit and the dent block may be used to accomplish this.

c) After firing test, the block shall be cleaned of foreign deposits. The dent in the block shall be measured by comparing at least two reference measurements on the block surface, taken far enough from the dent to avoid any surface displacement due to the detonation, with deepest point of the dent. The average of these two readings is the depth of the dent.

6.3.7 VISAR

VISAR may be used to characterize and validate performance of a device producing a detonating flyer output. Output flyer velocity can also be determined using this technique. This, in turn, may be used to determine the flyer's shock input into the receptor charge and predict margin between the two. VISAR may also be used to certify detonator performance once initial acceptance parameters have been established.

6.3.8 Flash X-ray

Flash X-ray may be used to determine output flyer velocity of a device. This, in turn, may be used to determine the flyer's shock input into the receptor charge and predict margin between the two. Flash x-ray may also be used to certify detonator performance once initial acceptance parameters have been established.

6.3.9 Post-Fire Current Leakage

If the user has a concern for power supply energy drain due to a short within the EED, the EED shall be monitored for a post-fire short circuit. The performance specification shall specify requirements for this parameter.

6.3.10 Post-Fire Header/Bulkhead Integrity

When the device being tested, e.g. EED, TBI, etc., is used as a pressure-retaining device, the integrity of the header or bulkhead after firing shall be verified. This may be accomplished by a hydrostatic pressure test or by a gas (e.g. helium) leak test. The performance specification shall specify requirements for this parameter.

6.3.11 Safe and Arm Firing Test

S&A devices shall be fired using the predicted operating current. In the event of unknown operating current, the specified all-fire current shall be used. Half of the devices shall be tested with both detonators receiving current simultaneously. Half of the devices shall be tested with the detonators receiving current sequentially to demonstrate complete redundancy. A minimum of one minute shall be provided between the sequenced detonator firings.

Annex A Test Tables

A.1 Tables

Table A.1 — First Element Non-Destructive Acceptance Tests

Test	Method	EED, SCB, HVD, EFI		Laser Initiator (%)	Mechanical Initiator (%)
		No Spark Gap (%)	With Spark Gap (%)		
Visual	101	100	100	100	100
Dimensional	102	100	100	100	100
Seal Effectiveness	103	100	100	100	100
Bridgewire Resistance	104	100	100[b]		
Thermal Transient	105	100[a]			
Resonant Frequency Measurements	106		100		
Spark Gap Breakdown	107		100		
Laser Optical Time Domain Reflectometer	108			100	
Dielectric Strength[c]	109	100	100		
Insulation Resistance	110	100	100		
X-Ray	111	100	100	100	100
N-Ray	112	100	100	100	100

[a] Test is optional.

[b] Test may be performed prior to bridgewire assembly with spark gap.

[c] To be performed to high voltage EEDs.

Table A.2 — S&A Non-Destructive Acceptance Tests

Test	Method	Quantity (%)
Visual	101	100
Dimensional	102	100
Seal Effectiveness	103	100
Bench Test	113	100
Acceptance Thermal Cycle	114	100
Acceptance Vibration	115	100
X-ray Inspection	111	100
Bench Test	113	100
Seal Effectiveness	103	100

Table A.3 — Other Device Non-Destructive Acceptance Tests

Test	Method	Quantity (%)
Visual	101	100
Dimensional	102	100
Seal Effectiveness	103	100
X-Ray	111	100
N-Ray	112	100

Table A.4 — EED, EFI, SCB, EBW, & LID Qualification Tests

Test	Method	Test Group I	II	III	IV	V	VI	VII[d]	VIII
		Number of Units to be Tested							
Non-Destructive Acceptance Tests	Table A.1	a	b	c	5	5	64	30	6
RF Impedance	212	10							
RF Sensitivity	213	a							
No-Fire Statistical	210		b						
All-Fire Statistical	211			c					
Tensile Load	201					5			
13.3 Meter Drop	208				5				
2 Meter Drop	207					5			
High Temperature Storage	209							30	
Thermal Cycling	204					5	64	30	6
Electrostatic Discharge	203					5	64	30	6
Shock	205					5	64	30	
Vibration	206					5	64	30	
Non-Destructive Acceptance Tests	Table A.1					5	64	30	6
1 Amp / 1 Watt No-Fire	202					5	64	30	6
Firing Tests									
Sure-Fire Input									
High Temperature						2	10	3	
Ambient Temperature						1	10	4	6
Low Temperature						2	10	3	
Operational Input									
High Temperature							8	3	
Ambient Temperature							8	4	
Low Temperature							8	3	
Maximum Operating Margin Input									
High Temperature							3	3	
Ambient Temperature							4	4	
Low Temperature							3	3	
Post-Fire Current Leakage [e]	6.3.9					5	64	30	6
Post-Fire Integrity [f]	6.3.10					5	64	30	6

[a] Quantity of components required for RF Sensitivity testing.

[b] Quantity of components required for All-Fire Statistical testing.

[c] Quantity of components required for No-Fire Statistical testing.

[d] This test provides an initial service life of 3 years. If the program does not need a 3-year life and never intends to perform this testing for life extension, testing for this group will become identical to that for Group VI.

[e] Required for all units for which post-fire current leakage could result in detrimental drain of battery energy.

[f] Required for all units which will be required to retain gas pressure after firing.

Table A.5 — S&A Qualification Tests

		Test Group				
		I	II	III	IV	V
Test	**Method**	**Number of Units to be Tested**				
Non-Destructive Acceptance Tests	Table A.2	[a]	1	3		
Extended Stall	216		1			
13.3 Meter Drop	208		1			
Containment	217			1		
Barrier Functionality	218			2		
Safing Verification	219				2	4
Interlock Verification	220				2	4
Bench Test	113				2	4
Cycle Life	214				2	
2 Meter Drop	207				1	4
Thermal Cycle	204				2	4
Shock	205				2	4
Vibration	206				2	4
Explosive Atmosphere	221				2	
Stall	222				2	4
S&A Interlock	220				2	4
X-ray Inspection	111				2	4
Seal Effectiveness	103				2	4
Internal Inspection	215				2	
Firing Tests						
High Temperature						2
Low Temperature						2

[a] Quantity of components required for Barrier Alignment Statistical Testing.

Table A.6 — Other Device Qualification Tests

Test	Method	Other Devices Test Group			S&A Rotor Leads and Boosters Test Group	
		I	II	III	I	II
		Number of Units to be Tested			Number of Units to be Tested	
Non-Destructive Acceptance Tests	Table A.3	1	21	6	6	21
13.3 Meter Drop		1				
2 Meter Drop			5			
Tensile Load[a]	201		21			
High Temperature Storage[b]	209		10			10
Thermal Cycle	204		21	6	6	21
Shock	205		21			21
Vibration	206		21			21
Non-Destructive Acceptance Tests	Table A.3		21	6	6	21
Firing Tests						
High Temperature			7	2	2	7
Ambient Temperature			7	2	2	7
Low Temperature			7	2	2	7
Post-Fire Integrity [c]	6.3.10		21	6		

[a] Applicable to ETA, LSCA, LPI.

[b] This test provides an initial service life of 3 years. If the program does not need a 3 year life and never intends to perform this testing for life extension, this testing may be deleted.

[c] Required for all units which will be required to retain gas pressure after firing.

Table A.7 — EED, EFI, SCB, EBW, & LID Destructive Acceptance Tests

Test	Method	Units Tested [a]
Non-Destructive Acceptance Tests	Table A.1	X
Tensile Load	201	X
High Temperature Storage	209	10[b]
Thermal Cycling	204	X
Shock	205	X
Vibration	206	X
Electrostatic Discharge	203	X
Non-Destructive Acceptance Tests	Table A.1	X
1 Amp / 1 Watt No-Fire	202	X
Firing Tests		
Sure-Fire Input		
High Temperature		c
Ambient Temperature		c
Low Temperature		c
System Operating Input		
High Temperature		c
Ambient Temperature		c
Low Temperature		c
Post-Fire Current Leakage[d]	6.3.9	X
Post-Fire Integrity [e]	6.3.10	X

[a] Total sample size shall be 30 units or 10% of production lot, whichever is greater.

[b] This test provides an initial service life of 3 years. If the program does not need a 3-year life and never intends to perform this testing for life extension, this testing may be deleted. These units shall be fired with the sure-fire input, three units at high temperature, four units at ambient temperature, and three units at low temperature.

[c] Quantity shall be 1/6 of sample size. Test quantity shall include those units from high temperature storage.

[d] Required for all units for which post-fire current leakage could result in detrimental drain of battery energy.

[e] Required for all units that will be required to retain gas pressure after firing.

Table A.8 — Other Device Destructive Acceptance Tests

Test	Method	Units Tested [a]
Non-Destructive Acceptance Tests	Table A.3	X
High Temperature Storage	209	X[b]
Thermal Cycle	204	X
Shock	205	X
Vibration	206	X
Non-Destructive Acceptance Tests	Table A.3	X
Firing Tests		
High Temperature		c
Ambient Temperature		c
Low Temperature		c

[a] Total sample size shall be 9 units or 10% of production lot, whichever is greater.

[b] This test provides an initial service life of 3 years. If the program does not need a 3 year life and never intends to perform this testing for life extension, this testing may be deleted.

[c] Quantity shall be 1/3 of sample size.

Table A.9 — EED, EFI, SCB, EBW, and LID Service Life Extension Tests

		Life Extension Length (Total Sample Size)	
		1 Year (5)	3 Years (10)
Test	**Method**	**Number of Units to be Tested**	
Non-Destructive Acceptance Tests	Table A.1	5	10
High Temperature Storage	209		10
Electrostatic Discharge	203	5	10
Thermal Cycling	204	5	10
Shock	205	5	10
Vibration	206	5	10
Non-Destructive Acceptance Tests	Table A.1	5	10
1 Amp / 1 Watt No-Fire	202	5	10
Firing Tests			
Sure-Fire Input			
High Temperature		2	4
Ambient Temperature		1	2
Low Temperature		2	4
Post-Fire Current Leakage [a]	6.3.9	5	10
Post-Fire Integrity [b]	6.3.10	5	10

[a] Required for all units that will be required to retain gas pressure after firing.

[b] Required for all units that will be required to retain gas pressure after firing.

Table A.10 —Other Device Service Life Extension Tests

Test	Method	Life Extension Life (Total Sample Size) 1 Year (5)	3 Year (10)
		Number of Units to be Tested	
Non-Destructive Acceptance Tests	Table A.3	X	X
High Temperature Storage	209		X
Thermal Cycle	204	X	X
Shock	205	X	X
Vibration	206	X	X
Non-Destructive Acceptance Tests	Table A.3	X	X
Firing Tests			
High Temperature		2	4
Ambient Temperature		1	2
Low Temperature		2	4
Post-Fire Integrity[a]	6.3.10	5	10

[a] Required for all units that will retain gas pressure after firing.

Annex B Non-Destructive Inspections and Test

B.1 Method 101 – Visual Inspection

B.1.1 Purpose

The purpose of this method is to verify that explosive system components or assemblies conform to product specification physical descriptions and that supporting documentation is available and complete.

B.1.2 Procedure

Visually inspect components or assemblies to verify that good workmanship was employed during manufacture and that the component is free of any physical defect that could adversely affect performance. Compare inspection results with product specification descriptions or detailed engineering requirements.

Inspection shall include verification of correct identification tags or labels that contain adequate information for configuration control and tracing of the item. This shall include as a minimum:

— Component / Assembly name, part number, lot number, and serial number

— Manufacturer identification

— Date of manufacture

Visual examination may include the use of optical magnification, mirrors, or specific lighting such as ultraviolet illumination.

Review supporting manufacturing, inspection, and test documentation for completeness.

B.1.3 Acceptance Criteria

Accept all items that conform to product specifications or engineering requirements and have complete document packages. Rejects may be reworked and re-inspected. Documentation of rework shall be included with appropriate data packages that accompany components or assemblies.

B.2 Method 102 – Dimensional Inspection

B.2.1 Purpose

The purpose of this method is to verify that the physical dimensions of explosive system components or assemblies conform to product specification descriptions.

B.2.2 Procedure

Using product specification dimensional descriptions or detailed engineering dimensional requirements, physically measure dimensioned features on each item and compare to requirements.

B.2.3 Acceptance Criteria

Accept all items that conform to product specifications or engineering requirements. Rejects may be reworked and re-inspected. Documentation of rework shall be included with appropriate data packages that accompany components or assemblies.

B.3 Method 103 – Seal Effectiveness

B.3.1 Purpose

The purpose of this method is to verify that the explosive device is effectively sealed from external environmental contamination.

B.3.2 Procedure

Existing leak test methods may not properly identify a gross leak rate for small internal free-volume devices, e.g. many explosive devices. Current methods for identifying gross leaks involve the use of liquids or dye penetrants, which are considered unacceptable for use with explosive devices. Explosive devices shall therefore be subjected to the following three types of leak inspections and tests to ensure proper seal.

B.3.2.1 In-Process Flow Through Leak Test

During manufacturing of many devices, part of the interfaces are sealed prior to final sealing of the device (e.g. glass sealed header for EEDs, bulkhead in TBIs, seal at one end of an explosive column welded in place prior to loading of explosives and welding of seal at opposite end, etc). For these types of devices, a flow through leak test shall be performed. This method is described in MIL-STD-202, Test Condition C, Procedures I and II.

B.3.2.2 Visual Gross Leak Identification

No tests involving liquids or dye penetrants shall be utilized with loaded explosive devices.

Final seals shall be visually inspected with 10X magnification for any discontinuities, interrupts, voids, cracks, or other imperfections which could result in leakage in the gross leak range, i.e. leaks that may not be detectable by a tracer gas test.

B.3.2.3 Seal Test

Seal test shall be accomplished using either a tracer gas (helium) method or a radioisotope method. Details of these methods are provided below.

B.3.2.3.1 Helium Tracer Gas

This method uses a mass spectrometer type leak detector connected to a chamber into which the devices under test are placed for the leak test. The volume of this chamber shall held minimum practical, since larger chamber volumes may adversely effect the ability of the leak detector to accurately measure leaks. The leak detector shall be calibrated at least once during every work shift using a diffusion-type calibrated standard of leak rate approximately 5 x 10 -6 std cm^3/s helium.

The completed device(s) shall be first placed in a sealed pressurization chamber, which shall be evacuated to a pressure of 25 mm of mercury (absolute) or less for a minimum of five minutes. The chamber shall then be backfilled with the tracer gas, 95% to 100% helium, at a pressure and for the duration shown in Table B-1. Upon completion of the bombing process, the pressure shall be reduced to ambient pressure and the devices transferred to the leak test chamber, which is connected to the leak detector. When this chamber is evacuated, any tracer gas, which was previously forced into the specimen, will be drawn out and measured by the leak detector. All devices shall be leak tested within 10 minutes after reduction of bomb pressure to ambient pressure.

Table B.1 — Leak Rate Requirements or Various Leak Test Parameters.

Device Internal Free Volume (cm^3)	Bomb Conditions		Maximum Time from Completion of Bombing to Completion of Leak Test (minutes)	Maximum Allowable Measured Leak Rate (Std cm^3/sec of helium)
	Minimum Helium Pressure (atm absolute)	Minimum Exposure Time (hours)		
< 0.05	3.0	1	10	4.3 X 10^{-6}
> 0.05 < 0.1	3.0	1	10	2.4 X 10^{-6}
> 0.1 < 0.2	3.0	1	10	1.3 X 10^{-6}
> 0.2 < 0.3	3.0	2	10	1.7 x 10^{-6}
> 0.3 < 0.4	3.0	2	10	1.3 x 10^{-6}
> 0.4 < 0.5	3.0	3	10	1.5 X 10^{-6}
> 0.5 < 1.0	3.0	4	10	1.0 X 10^{-6}

NOTE For a given actual leak rate, in order to achieve an approximately the same partial pressure of the tracer gas inside the device for indicating the listed leak rate, higher bomb pressure and/or longer bomb time are used for a device with larger free volume. For internal free volumes greater than 1 cm^3 and for intermediate volumes in the table above, the equation of MIL-STD-202G, paragraph 5.4.3.2.3, may be utilized to calculate bomb pressures and times and corresponding maximum allowable measured leak rates. Since the leak rate requirement herein is being specified in terms of std cm^3/ sec of helium, the equation assumes a ratio of '1' for molecular weights of specified gas and tracer gas.

B.3.2.3.2 Radioisotope

This method uses a Krypton85 leak detection system where the parts are placed in a chamber, evacuated and then pressurized at 3.0 atm absolute with the tracer gas. The tracer gas is returned to storage, the tank vented to atmosphere, the parts removed from the pressurization chamber and measured for detection of any radioactive tracer gas that has entered through a leak and is entrapped within the device. This measurement shall be completed within 10 minutes, and any device measuring 1,000 counts per minute above ambient background shall be rejected. A pressurization time of 2 minutes with a Krypton85 tracer gas concentration of 100 μCi/(atm $\cdot$ cm^3) will provide a sensitivity of 1 x 10^{-6} std cm^3/sec of krypton. The detection system calibration shall be performed once every shift following the procedures in MIL-STD 750D, Method 1071.7.

Small cavity devices, (< 0.2 cm^3), shall be tested following this procedure if they contain a gettering medium such as charcoal, or can show rejection when a 0.005 inch to 0.010 inch hole is penetrated into the device cavity. These devices shall be measured within 10 minutes after removal from the pressurization chamber.

A test method shall be selected from:

- MIL-STD-750D, Method 1071.1, Test Condition B or G
- MIL-STD-202G, Method 112E, Test Condition C, Procedure IIIb

B.3.2.3.3 Acceptance Criteria

For visual gross leak identification no discontinuities, interrupts, voids, cracks, or other imperfections which could result in leakage in the gross leak range shall be allowed.

Accept devices which exhibit a leak rate less than 5 X 10^{-6} std cm^3 / sec of helium.

Accept S&As which exhibit a leak rate less than 1 X 10^{-4} std cm^3 / sec of helium.

B.3.2.3.4 Applicable Documents

MIL-STD-202 Test Methods for Electronic and Electrical Component Parts

MIL-STD 750, Hermeticity of Semiconductor Devices with Designed Internal Cavities

ASTM E 493, Standard Test Methods for Leaks Using the Mass Spectrometer Leak Detector in the Inside-Out Testing Mode

B.4 Method 104 – Bridgewire Resistance

B.4.1 Purpose

The purpose of this method is to verify that resistance measurements of bridgewire elements of each EED are within product specification limits.

B.4.2 Procedure

Resistance of each EED bridgewire shall be measured using a remote electrical test circuit. The test circuit design shall be verified before use to have an electrical current limit of 10 mA or 1% of no-fire current whichever is less measured at the bridgewire. The open circuit voltage of the test equipment shall not exceed 10 mV (3.5 volts). Duration of application of current to the bridgewire during this measurement shall not exceed 60 sec. There shall be a 5 minute delay between repetitive measurements of any one bridgewire.

B.4.3 Acceptance Criteria

Accept all items that conform to product specifications or engineering requirements.

B.5 Method 105 – Thermal Time Constant

B.5.1 Purpose

The purpose of this test is to measure the thermal time constant of the EED. This test can provide information on the EED bridgewire weld joint, the bridgewire/explosive interface condition and possibly, the presence of volatiles in the explosive.

This test method helps identify out of family units, which may result in a dispersion of performance data which is too wide to meet acceptance criteria. This technique modifies the performance distribution since the tails of the distribution have been severely limited. This has the effect of making the distribution much narrower than would be indicated by a standard statistical test that concentrates its measurements in the center of the distribution.

B.5.2 Procedure

a) Measure the temperature increase in the bridgewire made from an alloy with positive temperature coefficient of resistivity when a constant current is passed through it for up to 100 milliseconds. For a one amp / one watt no-fire EED the current shall be one amp. The temperature rise is measured by using a constant current pulse and measuring the voltage, V, across the bridgewire as a function of time, t. The voltage change is proportional to the resistance change and the temperature change in the bridgewire.

b) Time constant, τ , is the time from time zero, t_o , to the 1/e point, t_1 , of the quasi inverse exponential curve of voltage increase across the bridgewire due to the increase of bridgewire resistance under constant current heating. The initial rate of change is steep as the bridgewire is heating up adiabatically. As time progresses, the rate decreases due to heat transfer into the explosive surrounding the bridgewire. Eventually, a steady state is reached where little or no change is observed.

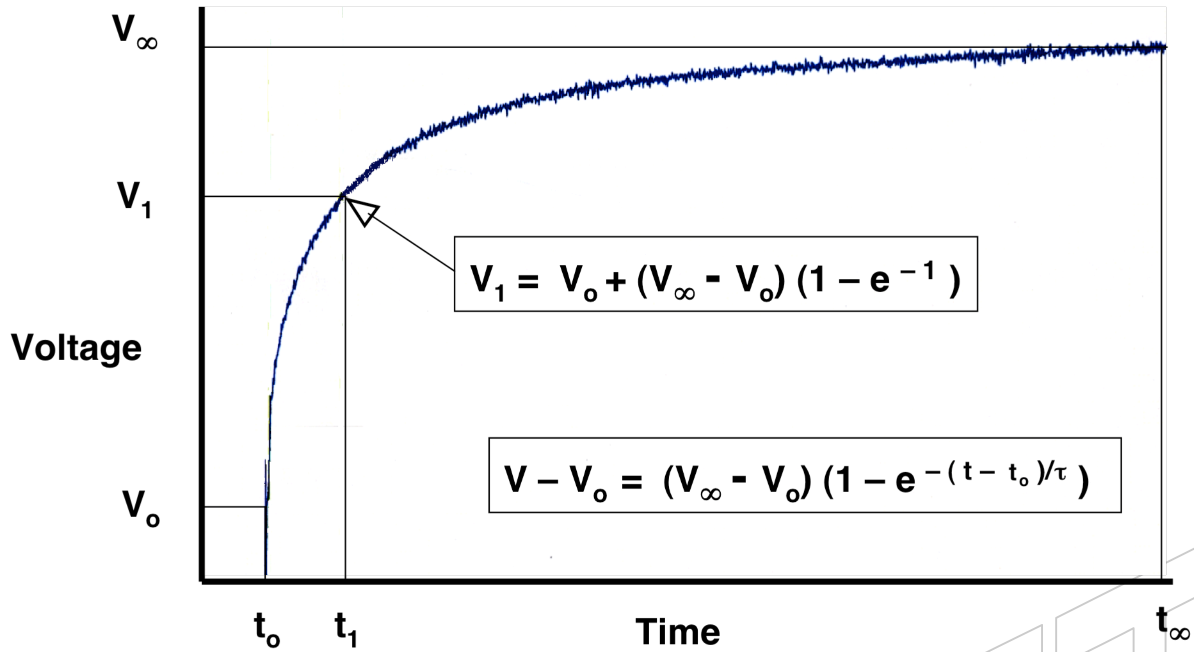

Figure B.2 —Representative Thermal Time Constant Test Data (ref. AIAA-2003-5139 Figure 10, Copyright, AIAA)

NOTE Time zero, t_o , is the onset time of the step constant current pulse. t_∞ is the time at which the voltage reaches a steady state. Because of the exponential functional form is only an approximation, small but measurable voltage increase may be a prolonged phenomenon. For practicality, the time can be chosen to be approximately at least ten times of the time constant under measurement. V_o is the voltage at time zero. It equals to the ambient temperature bridgewire resistance multiplied by the current.

a) The sharp rise rate of the onset of the constant current pulse at times can induce a short duration transient voltage spike in the measured voltage near the time zero. It is customary to ignore the first millisecond for discounting this signal interference as the procedure will not affect the usefulness of the measurement, which is focused in the time domain from one millisecond up to 100 milliseconds as illustrated in Fig. B.2.

b) Since the pulse is short and total energy low, the measurement may be repeated after a few seconds when temperature equilibrium has been reestablished.

B.5.3 Acceptance Criteria

Accept all items that do not exhibit anomalous test waveforms or out-of-family thermal time constant.

B.6 Method 106 – Resonant Frequency Measurement

B.6.1 Purpose

The purpose of this method is to verify that measured resonant frequencies of each EED design having high voltage breakdown gaps in conductive paths are within product specification limits. Resonant frequency measurement is used to verify the health of the EED conductor and bridgewire circuit via a gap in the circuit.

B.6.2 Procedure

Resonant frequency of each EED shall be measured using a remote test circuit. The test circuit design shall be verified before use to have an electrical current limit of 500 μA to the EED conductors. Testing shall ensure that readings taken after initial reading recorded during acceptance testing do vary from that reading by more than 5 MHz.

The resonant frequency test has been demonstrated to not provide high fidelity data on the EED electrical internal electrical circuit, i.e. pins, gap, bridgewire, etc. Significant changes in bridgewire resistance can occur without this test identifying the change.

Other test methods may be developed to replace this test. For example, header capacitance or complex impedance measurements may be made during acceptance and these measurements used as baseline for subsequent testing. The RF impedance test of Method 212 may be a good replacement for this test.

B.6.3 Acceptance Criteria

Acceptance criteria shall be established for each EED design and the test method chosen for use. Reject criteria shall ensure that any changes from EED baseline design, which may impact performance, are effectively screened.

B.7 Method 107 – Spark Gap Breakdown

B.7.1 Purpose

The purpose of this method is to verify that the magnitude of the voltage needed to arc across a spark gap in the conductive circuit of each EED is within product specification limits. Spark gap breakdown voltage measurement is used to verify health of the EED circuit.

B.7.2 Procedure

Spark gap breakdown voltage of each EED shall be measured using a remote test circuit. The test circuit design shall be configured to input voltage to the EED conductors in a manner that slowly ramps upward until arcing occurs. The test set-up shall be capable of capturing the voltage level at which arcing occurs. Maximum peak pulse current delivered to the device bridgewire shall be less than 0.5 A or 1.0 A in pulse duration less than 0.2 ms or 1/100 of bridgewire no fire current level, whichever is less. Measurements shall be repeated at least five times and the mean of these values used for comparison with product specification limits.

B.7.3 Acceptance Criteria

Accept all items that conform to product specifications or engineering requirements.

B.8 Method 108 – Laser Optical Time Domain Reflectometry Measurements

B.8.1 Purpose

The purpose of this method is to verify that the time and amplitude of reflected light wave transmission for each LID design is within product specification limits. Reflected light wave measurement is used to verify the health and continuity of fiber optic conductors/connectors within a LID circuit.

B.8.2 Procedure

Reflected light wave intensity of each EED shall be measured using a remote test circuit. A test circuit known as an OTDR shall be used. The OTDR design shall be verified to limit energy density input to LID explosive material interfaces to less than 1% of the minimum no-fire energy or power rating of LID for the pulse duration and wavelength used in the OTDR. OTDR measurements shall be repeated at least five times for each LID and the mean of these values used for comparison with product specification limits.

B.8.3 Acceptance Criteria

Accept all items that conform to product specifications or engineering requirements.

B.9 Method 109 – Dielectric Strength

B.9.1 Purpose

The purpose of this method is to verify dielectric strength between electrically conductive paths and between electrically conductive paths and case of high voltage EED designs to be within product specification limits.

B.9.2 Procedure

Dielectric strength shall be measured using a remote electrical test circuit capable of supplying at least 3000 VDC between pins and between pins and device body continuously. Test duration shall that which obtains a stable reading.

The test method and equipment shall be designed to prevent erroneous measures of current leakage, to the extent practical.

B.9.3 Acceptance Criteria

The dielectric in the unit under test shall not breakdown.

B.10 Method 110 – Insulation Resistance

B.10.1 Purpose

The purpose of this method is to verify resistance between insulation and electrically conductive paths of low and high voltage EED designs to be within product specification limits.

B.10.2 Procedure

Resistance of each EED insulation feature shall be measured using a remote electrical test circuit such as a Meg-ohm bridge meter or a unique insulation resistance test set.

The test method and equipment shall be designed to prevent erroneous measures of current leakage, to the extent practical. The measurements shall be made between mutually insulated points of the EED, and between these points and ground. Test duration shall that which obtains a stable reading. The applied voltage shall be no less than 500 VDC for high voltage EED designs and no less than 250 VDC for low voltage EED designs. For low voltage EED designs, the initial measurement made during acceptance testing shall be made with at least 250 VDC; subsequent readings shall be made with no less than 50 VDC or 2 times of maximum system voltage. The measured insulation resistance shall be greater than 2 MΩ for low voltage EEDs and 20 MΩ for high voltage EEDs. Other voltage and insulation values may be used as dictated by EED design specifications.

B.10.3 Acceptance Criteria

Accept all items that conform to product specifications or engineering requirements.

B.11 Method 111 – X-ray Radiographic Inspection

B.11.1 Purpose

The purpose of this method is to verify that metallic-based elements of explosive system components and assemblies are properly aligned, assembled, or positioned and that no apparent defects are present as compared with product specification descriptions.

B.11.2 Procedure

B.11.2.1 Technique Sheet

Process technique sheets shall include sufficient controls and parameters from the reference standard or specification to properly ensure the process is robust, repeatable, and provides adequate resolution of attributes to be inspected. Individual or groups of components or assemblies shall be subjected to the following operations:

B.11.2.2 Positioning

Components or assemblies shall be positioned to minimize parallax effects. Multiple orthogonal views shall be considered based on degree of inspection desired or on the complexity of items.

B.11.2.3 Image quality

To X-ray inspection shall be performed per ASTM E 1742. Intensity, brightness, resolution, and contrast shall be adjusted to best define features to be inspected. Multiple radiographs having varying degrees of exposure or having views from different angles may be required to allow complete coverage of internal parts. Non-film recording media can include digital imaging when approved by procuring authority.

B.11.2.4 Identification

Each radiograph shall include all appropriate part, production lot, and serial numbers describing the items inspected as a permanent part of the film.

B.11.2.5 Radiographic Inspector

Radiographs shall be evaluated by a certified inspector.

B.11.3 Acceptance Criteria

Accept all items that conform to acceptance criteria. Rejects that can be reworked shall be recycled through the appropriate nondestructive test series, if practical. Documentation of rework shall be included with appropriate data packages that accompany components or assemblies.

B.11.4 Applicable Documents

ISO Standard 5579:1998, *Nondestructive* testing – Radiographic examination of metallic materials by X- and gamma rays – Basic rules

ASTM E 1742: Standard Practice for Radiographic Examination

B.12 Method 112 – N-ray Radiographic Inspection

B.12.1 Purpose

The purpose of this method is to verify that nonmetallic based elements of explosive system components and assemblies are properly aligned, assembled, or positioned and that no apparent defects, e.g., voids and foreign objects are present in the explosive, as compared with product specification descriptions.

B.12.2 Procedure

Test Procedure containing detailed descriptions of inspection procedure, measuring equipment to be used, and acceptance criteria.

B.12.2.1 Technique Sheet

Process technique shall include sufficient controls and parameters from the reference standard or specification to properly ensure the process is robust and repeatable and provides adequate resolution of attributes to be inspected. Individual or groups of components or assemblies shall be subjected to the following operations:

B.12.2.2 Positioning

Components or assemblies shall be positioned to minimize parallax effects. Multiple orthogonal views shall be considered based on degree of inspection desired or on the complexity of items.

B.12.2.3 Image quality

N-ray inspection shall conform to the requirements of ASTM E 748. Intensity, brightness, resolution, and contrast shall be adjusted to best define features to be inspected. Multiple radiographs having varying degrees of exposure or having views from different angles may be required to allow complete coverage internal parts.

B.12.2.4 Identification

Each radiograph shall include all appropriate part, production lot, and serial numbers describing the items inspected as a permanent part of the film.

B.12.2.5 Radiographic Inspector

Radiographs shall be evaluated by a certified inspector.

B.12.3 Acceptance Criteria

Accept all items that conform to success criteria. Rejects that can be reworked shall be recycled through the appropriate nondestructive test series, if practical. Documentation of rework shall be included with appropriate data packages that accompany components or assemblies.

B.12.4 Applicable Documents

ISO Standard 11537, *Nondestructive testing –Thermal neutron radiographic testing – General principles and basic rules*.

ASTM E 748, Standard Practices for Thermal Neutron Radiography of Materials

B.13 Method 113 – S&A Bench Test

B.13.1 Purpose

The purpose of this method is to verify that S&A cyclic and safing pin functions, and electrical resistance repeatability are within product specification limits. These tests and inspections can be used throughout S&A service life as means to check electro-mechanical function. These have been referred to as bench tests.

B.13.2 Procedure

The following operations and inspections shall be performed on each S&A using a remote test set that can supply nominal input voltage, measure safe-to-arm-to-safe cycle times, measure insulation and bridgewire resistance of all S&A circuits, and electronically verify safe and arm positions. Bridgewire and insulation resistance measurements shall conform to Methods 104 and 110, respectively. The total number of cyclic functions performed during these operations shall be recorded and added to the cumulative total listed in supporting data packages that shall accompany each S&A.

a) Apply arm power and ensure safing pin cannot be removed from S&A. Remove arm power.

b) Manually remove safing pin from S&A. Ensure pin is easily removed with no binding.

c) Remotely position S&A to arm mode using nominal input electrical voltages. Measure and record cycle time from safe to arm positions. Compare measured time with product specification limits. Visually and electronically verify that arm indications are correct.

d) Measure and record all pertinent insulation and circuit resistance values. Compare with product specification limits.

e) Remotely position S&A to safe mode using nominal input electrical voltages. Measure and record cycle time from arm to safe positions. Compare measured time with product specification limits. Visually and electronically verify that safe indications are correct.

f) Measure and record all pertinent insulation and circuit resistance values of all circuits. Compare with product specification limits.

g) Cycle S&A from safe to arm to safe modes 25 times using nominal input voltages. Measure and record cycle time from safe to arm and from arm to safe and compare with product specification limits. Visually and electronically verify that safe or arm indications are correct.

h) Measure and record all pertinent insulation and circuit resistance values of all circuits. Compare with product specification limits.

i) Remotely position S&A to arm mode using nominal input electrical voltages. Measure and record cycle time from safe to arm positions. Compare measured time with product specification limits. Visually and electronically verify that arm indications are correct.

j) Measure and record all pertinent insulation and circuit resistance values of all circuits. Compare with product specification limits.

k) Manually position the S&A to the safe mode using the safing pin. Visually and electronically verify that arm indications are correct.

B.13.3 Acceptance Criteria

Accept all items that conform to product specifications or engineering requirements.

B.14 Method 114 – S&A Acceptance Thermal Cycle

B.14.1 Purpose

The purpose of this method is to verify the workmanship by exposing each S&A to acceptance level thermal cycle environments.

B.14.2 Procedure

S&As shall be subjected to 8 thermal cycles defined as follows.

a) Starting from an ambient temperature condition, elevate the chamber temperature at a rate of at least 3°C per minute to 61°C or to the maximum predicted operating temperature, as determined by the end item application, whichever is greater.

b) Dwell at this temperature for a minimum of 2 hours.

c) Following the dwell period, reduce the temperature at a rate of at least 3°C per minute until reaching –24°C, or the minimum predicted operating temperature, as determined by the end item application, whichever is less.

d) Dwell at this temperature for 2 hours.

e) Following the dwell period, elevate the chamber temperature at a rate of at least 3°C per minute until the original ambient temperature condition is reached.

f) Continue the cyclic process from this point until the proper quantity is completed.

g) Continuity and isolation of S&A circuits shall be monitored continuously during last high and low temperature dwells.

B.14.3 Acceptance Criteria

The test unit shall demonstrate acceptable performance verification results during testing. The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections.

B.15 Method 115 – S&A Acceptance Vibration

B.15.1 Purpose

The purpose of this method is to verify the workmanship by exposing each S&A to acceptance level random vibration environments.

B.15.2 Procedure

For any S&A that is mounted on one or more vibration or shock isolators during flight, the component shall undergo vibration testing in the same bracket/isolator mounted configuration, or hard mounted to an environment which accounts for isolator attenuation and adds a 1.5 dB margin to account for isolator variability. Subject each test setup to a random vibration environment that is equivalent to the MPE of the end item application but not less than the minimum frequency versus power spectral density envelope described in the table below. The environment shall be applied to three orthogonal axes of the S&A for 1 minute at each axis minimum. The S&A performance, bridgewire resistance, and status of health parameters shall be continuously monitored during testing. Monitoring shall have a sample rate of once every millisecond or better.

Table B.2 — Minimum Frequency Versus Power Spectral Density

Frequency, Hz	Power Spectral Density, Minimum
20	0.0053 g^2/Hz
20-150	Slope of 3 dB/Octave
150-600	0.046 g^2/Hz
600-2000	Slope of - 6dB/Octave
2000	0.0036 g^2/Hz

B.15.3 Acceptance Criteria

The test unit shall demonstrate acceptable performance verification results during testing. The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections.

Annex C Destructive and Environmental Tests

C.1 Method 201 – Tensile Load

C.1.1 Purpose

The purpose of the following tests is to verify the capability of the components to withstand handling tensile loads without damage or degradation of performance.

C.1.2 Procedure

C.1.2.1 Electro-Explosive Device

EED pins, lead wires, and terminals shall be subjected to an axial pull of at least 18 lb for a minimum of 1 minute without damage or degradation in performance. When it is impractical to apply a direct pull on the EED pins the EED may be subjected to an internal pressure that would result in a 18 lb force being applied to the pin. This test may be performed during the manufacture process.

EEDs contained in a S&A may undergo additional testing once the EED is installed in the S&A in lieu of the 18 pound pull requirement.

C.1.2.2 ETA

These devices shall be subjected to a 100 lb tensile load for a minimum of 1 minute without damage or degradation in performance.

C.1.2.3 Destruct Charge

These devices shall be subjected to a 50 lb tensile load for a minimum of 1 minute without damage or degradation in performance.

C.1.3 Acceptance Criteria

The test unit shall not fail structurally or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections.

C.2 Method 202 – 1 AMP / 1 WATT No-Fire

C.2.1 Purpose

The purpose of the following test is to verify the capability of the EED to withstand the five minute application of the no-fire current/power without damage or degradation of performance.

C.2.2 Procedure

Subject each EED bridgewire to a 1 amp / 1 watt (+5% / -0%), whichever is greater, for a minimum of 5 minutes at laboratory ambient conditions. No external heat sinks are to be used during this test.

C.2.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections.

C.3 Method 203 – Electrostatic Discharge

C.3.1 Purpose

The purpose of this method is to verify that the magnitude of the voltage needed to arc between the EED pin and the EED case is within product specification limits for those EED designs that use the EED case as an element of the EED circuit. Breakdown voltage measurement is used to verify health of the EED circuit.

C.3.2 Procedure

Pin-to-case breakdown voltage of each EED shall be measured using a remote test circuit. The test circuit design shall be configured to input a 25 kV pulse from a 500 pF capacitor between shorted bridgewire pins and case, and a 25 kV pulse from a 500 pF capacitor through a 5 kΩ resistor applied across the bridgewire.

C.3.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections.

C.4 Method 204 – Thermal Cycle

C.4.1 Purpose

The purpose of this method is to expose explosive system components and assemblies to a qualification level cyclic thermal environment as part of qualification, destructive acceptance, and service life test programs.

C.4.2 Procedure

C.4.2.1 Components or Assemblies Except Those to be Installed in S&As

Components or assemblies, except those from production lots to be installed in S&As, shall be subjected to the greater of 8 complete cycles or 1.5 times the maximum number of cycles that the component could experience during launch processing and flight, including all launch delays and recycling.

C.4.2.2 Components to be Installed in S&As

Components or assemblies from production lots to be installed in S&As, e.g detonators, rotor leads, or booster charges, shall be subjected to 24 complete cycles of temperature exposures as described below.

a) Starting from an ambient temperature condition, elevate the chamber temperature at a rate of at least 3°C per minute to 71°C or to the maximum predicted operating temperature plus 10°C, as determined by the end item application, whichever is greater.

b) Dwell at this temperature for a minimum of 2 hours.

c) Following the dwell period, reduce the temperature at a rate of at least 3°C per minute until reaching –54°C, or the minimum predicted operating temperature minus 10°C, as determined by the end item application, whichever is less.

d) Dwell at this temperature for 2 hours.

e) Following the dwell period, elevate the chamber temperature at a rate of at least 3°C per minute until the original ambient temperature condition is reached.

f) Continue the cyclic process from this point until the proper quantity is completed.

C.4.2.3 Safe and Arms

S&As shall be subjected to 24 complete cycles of temperature exposures as described below.

In a suitable test chamber each component or assembly shall be exposed to a temperature cycle as defined by the following:

a) Starting from an ambient temperature condition, elevate the chamber temperature at a rate of at least 3°C per minute to 71°C or to the maximum predicted operating temperature plus 10°C, as determined by the end item application, whichever is greater;

b) Dwell at this temperature for a minimum of 2 hours;

c) Following the dwell period, reduce the temperature at a rate of at least 3°C/min until reaching –54°C, or the minimum predicted operating temperature minus 10°C, as determined by the end item application, whichever is less;

d) Dwell at this temperature for 2 hours;

e) Following the dwell period, elevate the chamber temperature at a rate of at least 3°C per minute until the original ambient temperature condition is reached; and,

f) Continue the cyclic process from this point until the proper quantity is completed.

Continuity and isolation of S&A circuits shall be monitored continuously during last high and low temperature dwells.

C.4.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections. S&As shall also demonstrate acceptable performance verification results during testing.

C.5 Method 205 – Shock

C.5.1 Purpose

The purpose of this method is to demonstrate the design and any item which attaches to it will satisfy all performance requirements after exposure to the qualification level shock environment.

C.5.2 Procedure

Subject each setup to a dynamic shock spectrum and transient that is at least 4.5 dB greater than the maximum predicted environment expected in the end item application. The minimum shock environment shall be 3 dB above MPE plus test tolerances for all frequencies from 100 Hz to 10000 Hz. The environment shall be applied three times in each direction along each of three orthogonal axes of the item tested. If no credible test data is available, 6dB shall apply.

C.5.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections.

C.6 Method 206 – Random Vibration

C.6.1 Purpose

The purpose of this method is to demonstrate the design and any item which attaches to it will satisfy all performance requirements after exposure to the qualification level shock environment.

C.6.2 Procedure

The test setup shall consist of the test item plus all attached items including isolators, brackets, grounding strap, ETA, or cable to the first tie-down. Subject each setup to a random vibration environment that is equivalent to the MPE of the end item application plus 4.5 dB but not less than the minimum frequency versus power spectral density envelope described in the table below. The minimum vibration environment shall be 3 dB above MPE plus test tolerances for all frequencies. The environment shall be applied to three orthogonal axes for 3 times of maximum predicted duration or 3 minutes at each axis, whichever is longer. If no credible test data is available, 6 dB shall apply.

C.6.2.1 Safe and Arm Testing

Prior to performance of qualification testing, S&As to be tested shall have been subjected to the S&A acceptance vibration test. S&A shall be in the armed condition during vibration test. For any S&A that is mounted on one or more vibration or shock isolators during flight, the component shall undergo vibration testing in the same bracket/isolator mounted configuration, or hard mounted to an environment which accounts for isolator attenuation and adds a 1.5 dB margin to account for isolator variability. S&A performance and status of health parameters shall be continuously monitored during testing with a sample rate capable of identifying switch chatter.

Table C.1 — Frequency Versus Minimum Power Spectral Density

Frequency, Hz	Power Spectral Density, Minimum
20	0.021 g^2/Hz
20-150	Slope of 3 dB/Octave
150-600	0.16 g^2/Hz
600-2000	Slope of - 6dB/Octave
2000	0.011 g^2/Hz

C.6.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections. For S&As, the test unit shall demonstrate acceptable performance verification results during testing.

C.7 Method 207 – 2 Meter Drop

C.7.1 Purpose

The purpose of this method is to demonstrate that the design will not initiate when exposed to a two meter drop and will satisfy all its performance requirements after experiencing the drop.

C.7.2 Procedure

Drop each unit 3 times onto a half inch thick steel plate from a height of 2 meters. One drop shall result in impact on the output end of the unit under test, one drop shall result in impact on the input end, and the remaining drop shall result in impact on the side, or as near to those ends as practical.

C.7.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage which would preclude further testing or nominal installation, and shall perform acceptably in all subsequent tests and inspections.

C.8 Method 208 – 13.3 Meter Drop

C.8.1 Purpose

The purpose of this method is to demonstrate that design does not initiate and remains safe for disposal after experiencing the maximum predicted drop and resulting impact that could occur during storage, transportation, or installation.

C.8.2 Procedure

Drop test unit onto a one half inch thick steel plate from a height of 13.3 meters.

C.8.3 Acceptance Criteria

Unit shall not rupture or fire and shall be safe for removal and disposal.

C.9 Method 209 – High temperature Storage

C.9.1 Purpose

The purpose of this method is to expose explosive system components and assemblies to an elevated temperature storage simulation test to provide longer service life during acceptance testing or accelerated age surveillance test program.

C.9.2 Procedure

To establish an initial life of three years or provide a three year service life extension, install the test units in a conditioning chamber and expose them to 71°C and 40 to 60% humidity for no less than 30 days. To establish a longer initial life or longer service life extension. See paragraph 6.1.2.5.2.

C.9.3 Acceptance Criteria

Accept or reject determinations will be made during subsequent performance measurement tests.

C.10 Method 210 – No-Fire Level

C.10.1 Purpose

This test shall consist of a statistical firing series to determine the no-fire energy level.

C.10.2 Procedure

The firing series shall determine the highest electrical energy level at which the device will not fire with a reliability of 0.999 at 95 % confidence level when subjected to a continuous current pulse. A statistical sampling scheme, such as Bruceton, Langlie, or Neyer, shall be used to demonstrate the required reliability. The firing pulse shall be a minimum of 5 minutes.

See Annex D for details regarding Statistical Methods.

C.10.2.1 Test Description

A 5 minute constant current pulse applied to the bridgewire of the EED shall be used as the stimulus in this test. The current pulse amplitudes to be used for the test are to be chosen based on the type of statistical test being performed. In the event of a no-fire the EED will not be disconnected from the system. A current pulse large enough to ensure firing shall be applied to the EED. If the EED still fails to fire, the no-fire data point will be omitted from the test and the reason for the no-fire determined and reported.

During testing each exposure shall be monitored to provide a permanent record of the voltage and current of the bridgewire during the 5 minute pulse. These records shall be retained by the facility performing the test.

C.10.2.2 Calculations

Computation of the statistical test results shall be made on both fire (X) and no-fire (0) data. Any deviation exceeding 10% between the X determined sigma and the 0 determine sigma will be sufficient to void the test and cause for rerun of the test. Tests showing less than 4 or greater than 7 or more levels shall also be considered void and the test must be rerun.

The 0.001 (0.1%) firing level of the EED, in amperes with 95% confidence, shall be computed from the test results.

C.10.3 Acceptance Criteria

None. Results will be used to determine the no-fire level of the EED.

C.11 Method 211 – All-Fire Level

C.11.1 Purpose

This test shall consist of a statistical firing series to determine the all-fire energy level.

C.11.2 Procedure

The firing series shall determine the lowest electrical energy level at which the device will fire with a reliability of 0.999 at 95 % confidence level when subjected to a continuous current pulse. A statistical sampling scheme, such as Bruceton, Neyer, or Langlie, shall be used to demonstrate the required reliability. The firing pulse shall be a constant current of 30 milliseconds.

See Annex D for details regarding Statistical Methods.

C.11.2.1 Test Description

A 30 millisecond constant current pulse applied to the bridgewire of the EED shall be used as the stimulus in this test. The current pulse amplitudes to be used for the test are to be chosen based on the type of statistical test being performed.

During testing each exposure shall be monitored to provide a permanent record of the voltage and current of the bridgewire during the 30 millisecond pulse. These records shall be retained by the facility performing the test.

C.11.2.2 Calculations

Computation of the statistical results shall be made on both fire (X) and no-fire (0) data. Any deviation exceeding 10% between the X determined sigma and the 0 determine sigma will be sufficient to void the test and cause for rerun of the test. Tests showing less than 4 or greater than 7 or more levels shall also be considered void and the test must be rerun.

The 0.999 (99.9%) firing level of the EED, in amperes with 95% confidence, shall be computed from the statistical test results

C.11.3 Acceptance Criteria

None. Results will be used to determine the all-fire level of the EED.

C.12 Method 212 – RF Impedance

C.12.1 Purpose

The purpose of this method is to to measure the radio frequency impedance of EEDs.

C.12.2 Procedure

The impedance measuring equipment shall function at extremely low radio frequency power levels so that the EEDs are not subjected to heating effects. No more than 1 milliwatt shall be applied to the EEDs in any firing mode during the measurements.

The mounting apparatus used to connect the EEDs to the impedance measuring apparatus shall be constructed so that the impedance measurements refer to a point as close to the base of the EEDs (exterior surface of the EED header) as is possible.

The minimum number of EEDs to be used in the impedance measurements is ten.

Impedances shall be measured for each potential firing mode of the EED. Pin-to-pin and pin-to-case impedances will be measured for 2-pin conventional hot wire EEDs. For dual bridge wire EEDs measurements will be performed in the pin-to-pin, pin-to-case and bridge-to-bridge firing modes.

Impedance measurements will be performed at 10 frequencies between 1 and 1200 MHz. The individual measurement frequencies should be selected so that neighboring frequencies differ from each other by an approximately equal logarithmic increment.

C.12.3 Acceptance Criteria

None. Results will be used in RF Sensitivity Test.

C.13 Method 213 – RF Sensitivity

C.13.1 Purpose

The purpose of this method is to measure the radio frequency sensitivity of EEDs and provide an RF no-fire level usable for RF hazard analyses.

C.13.2 Procedure

At each radio frequency to be used in the test, the radio frequency power to be applied to the EEDs is determined from the mean dc firing current measured in Method 210 and dc bridgewire resistance. This level shall be applied to the devices in each mode (i.e., pin-to-pin, pin-to-case, bridgewire-to-bridgewire).

Applied powers shall be demonstrated to be those actually delivered to the input of the EED. Mounting hardware for the EED shall be constructed to allow measurement of power as close to the EED base (exterior surface of the EED header) as possible.

At least 10 frequencies shall be used in the probing tests. These frequencies should be chosen to cover the frequency range from 1 MHz to 32 GHz and should include any frequency corresponding to a known high power density in the EEDs operational environment. Special consideration should be given to frequencies that correspond to transmitters associated with the overall system of which the EED is a part. If there are no specific requirements, the approximate frequency and modulation stimuli presented in Table C.2 shall be used.

See Annex D for details regarding Statistical Methods.

Table C.2 — Default Test Frequencies and Modulations

Frequency (Mhz)	Modulation
1.5	CW
27.0	CW
154.0	CW
250.0	CW
900.0	CW
2700.0	P
5400.0	P
8900.0	P
15,000.0	CW
32,000.0	P
P = Pulsed modulation with pulse width of 1 µs and pulse repletion rate of 1 KHz CW = Continuous Wave	

C.13.3 Acceptance Criteria

None. Results will be used to determine the RF no-fire level of the EED.

C.14 Method 214 – S&A Cycle Life

C.14.1 Purpose

The purpose of this method is to verify that each S&A design can survive 1000 safe to arm to safe cycles without malfunction, failure, or degraded performance.

C.14.2 Procedure

Using operational voltages electrically cycle the S&A from safe to arm and arm to safe. Continue this process until 1000 cycles have been completed. At cycles 500 and 1000 perform a Bench Test, Method 113 (without the 25 cycles from safe to arm to safe).

C.14.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage or degradation, and shall perform acceptably in all subsequent tests and inspections.

C.15 Method 215 – S&A Internal Inspection

C.15.1 Purpose

The purpose of this method is to disassemble and inspect internal elements of each S&A design after it was subjected to various tests. Assess the integrity of all sliding or rotating components, surfaces, and interfaces.

C.15.2 Procedure

Disassemble S&A and record the condition of all sliding or rotating components, surfaces and interfaces.

C.15.3 Acceptance Criteria

The S&A shall not show evidence of degradation or damage, which would preclude nominal operation and firing.

C.16 Method 216 – S&A Extended Stall

C.16.1 Purpose

The purpose of this method is to verify that each S&A design can survive the application of maximum arming voltage for 60 minutes minimum with safing pin installed without initiation of internal ordnance components.

C.16.2 Procedure

With safing pin installed, apply maximum arming voltage to the S&A arm circuit for a minimum of 60 minutes. Maximum arming voltage values shall be determined from end item application input limits.

C.16.3 Acceptance Criteria

The test unit shall not fire.

C.17 Method 217 – S&A Containment

C.17.1 Purpose

The purpose of this method is to verify that the S&A design can survive firing of internal ordnance components without emitting any external fragmentation.

C.17.2 Procedure

All internal ordnance components shall be simultaneously fired in the test unit that has the output ports sealed.

C.17.3 Acceptance Criteria

S&A housing shall remain intact and not emit any fragmentation.

C.18 Method 218 – S&A Barrier Functionality

C.18.1 Purpose

The purpose of this method is to verify that the S&A design will not propagate the output detonation signal to the ETA when the S&A is in the safe condition.

C.18.2 Procedure

The test shall include firings at the maximum predicted high temperature or 71°C whichever is greater, and at the minimum predicted low temperature or –54°C whichever is lower. The S&A under test shall have flight like ETA installed in output ports and the internal EEDs shall be simultaneously fired with the S&A in the following position.

a) For rotating barriers, the test unit rotor shall be positioned midway between the safe and arm positions.

b) For siding barriers the test unit barrier shall be positioned midway between the safe and the arm positions.

C.18.3 Accept/Reject Criteria

The S&A shall not initiate the ETA.

C.19 Method 219 – S&A Safing Verification

C.19.1 Purpose

The purpose of this method is to verify that the S&A design will not fire when in the safe condition.

C.19.2 Procedure

The unit under test shall have operational firing current applied to the firing circuits when in the safe condition. The current shall be applied for 15 seconds minimum.

C.19.3 Acceptance Criteria

The test unit shall not fire.

C.20 Method 220 – S&A Interlock Verification

C.20.1 Purpose

The purpose of this method is to verify the S&A's safing interlock design prevents arming when operational arming voltage is applied to the arming circuit.

C.20.2 Procedure

With safing pin installed, apply operational arming voltage to the S&A arm circuit and attempt to remove the safing pin with 100 pounds of tension or 100 inch-pounds of torque.

C.20.3 Acceptance Criteria

Removal of the safing interlock shall not be possible if the arming mechanism is energized.

C.21 Method 221 – S&A Explosive Atmosphere

C.21.1 Purpose

The purpose of this method is to verify the S&A design will not ignite an explosive atmosphere when rotated from arm to safe and back.

C.21.2 Procedure

Using operational voltages, the S&A shall be operated from safe to arm and back to safe 5 times in the fuel vapor laden environment which requires the least amount of energy for ignition.

C.21.3 Acceptance Criteria

The test unit shall not ignite the explosive atmosphere.

C.22 Method 222 – S&A Stall

C.22.1 Purpose

The purpose of this method is to verify that the S&A design can survive the application of operating arming voltage for 5 minutes minimum with safing pin installed without damage or degradation in performance.

C.22.2 Procedure

With safing pin installed, apply maximum arming voltage to the S&A arm circuit for a minimum of 5 minutes. Maximum arming voltage values shall be determined from end item application input limits.

C.22.3 Acceptance Criteria

The test unit shall not fire or show any evidence of damage, and shall perform acceptably in all subsequent tests and inspections.

Annex D All-Fire/No-Fire Test and Analysis Methods

D.1 Scope

This appendix offers test and analysis methods for estimating first element functional all-fire and non-functional no-fire input energy ratings. These are applicable to electrical, optical, and mechanical first elements. Reliability and safety issues necessitate use of methodologies that can ensure consistency in derivation of these estimates. Accepted test methods for estimating these parameters include the Bruceton, Langlie, and Neyer methods described here. Accepted analysis methods are also described.

D.2 Test Methods

Several test techniques can be used for evaluation of the relative sensitivity of first elements. This section describes the three most commonly used test methods. An introduction also describes the necessity of using a well-defined test method. The next section describes commonly used analysis methods. Although the test and analysis methods are in principle independent, each test method has historically been associated with one analysis method.

D.2.1 Introduction

The type of tests used to estimate first element functional all-fire and no-fire is known in the statistical literature as a sensitivity test. These types of tests are required for estimating the probability of functional performance for explosive components, because it is impossible to determine nondestructively whether an explosive device will function at a given stimulus level. The only thing that can be determined is whether a given device did or did not function at a given stimulus. Such a test is almost always destructive. If the device functioned it cannot be used again, if it failed to function, it is usually damaged so that it cannot be used or tested again. Moreover, the output of the device is generally independent of the input stimulus. Either the device functions or fails to function. Devices that have a one-shot test with output independent of input require the specialized test and analysis methods described here.

To conduct a test, the experimenter tests devices at various stress levels and notes whether they function or fail to function. Great care must be exercised when choosing the test levels. If all of the levels chosen are too low, then all of the devices will fail to function and little will be learned. A similar result occurs if the levels are all too high. Choosing levels tightly bunched at the 50 % point provides reliable estimates of the 50% point, but little about the probability of proper function in the extreme levels.

The objective of a sensitivity test is to choose the test levels wisely, so that analysis of the data yields estimates that are as accurate and precise as possible. The parameter to be estimated is generally the stimulus level at which some fraction of the samples of a specific first element design will always function, in the case of an all-fire test, or not function, in the case of a no-fire test. There are no methodologies capable of exact determinations of this value.

D.2.2 Limitations

All methods used are small sample based. Therefore error in the estimates may occur. Users of these computed values should be made aware that adding margin to estimated all-fire and no-fire values is standard practice. As noted in paragraph 4.4.1 of MIL-HDBK-83578, an ignition system should use input stimulus 1.25 times greater than the estimated all-fire threshold of the interfacing first element. For example, an EED having an all-fire estimate of 3.25 amperes for its ignition system should be designed to have a minimum input of 4.06 amperes.

All of the test methods also assume that the distribution of the threshold levels is a normal distribution. It is simple to generalize this assumption to require that some function (such as a logarithm) of the threshold levels is distributed normally.

D.2.3 General Test Procedures

Tests should be performed in an ambient temperature environment unless conditions anticipated in the end item application dictate a need to do otherwise. Heat sinks used should simulate thermal properties of the end item application to the extent practical. Once started, the test should continue uninterrupted until completed. Analysis can be performed at any time after completion of the test portion of the task. For EED and LID first elements, all-fire tests should use an ignition stimulus pulse duration equivalent to that used in the end item application, but should be no greater than 30 milliseconds. No-fire tests are not required for mechanical first elements.

D.2.3.1 Bruceton Test Procedure

The Bruceton test was developed by Dixon and Mood in 1948[1]. The goal of the procedure was to develop a method that allowed for simple pencil-and-paper analysis.

At least 45 first elements should be allocated for each test. The first sample is pulsed at a defined stimulus level and duration. If that sample fires, the next test sample is pulsed at a stimulus level and duration that is reduced by a defined increment lower than the first. If the first sample had not fired the next sample would have been pulsed with a stimulus increased by the same defined increment. The test continues in this process until at least 40 samples are expended. Each sample is pulsed only once during these tests.

The total number of incremental steps of fire and no fire data points must be between 4 and 6 inclusive if the specialized Bruceton analysis method is to be used. (Initial tests that guide the test level into the region of interest do not count towards these 4 to 6 levels.) Tests where the numbers of increment steps are outside this range these should be considered invalid.

To prevent invalid tests, care should be exercised in selecting the amount of the defined increment (step size) used. The test is only efficient if the step size matches the standard deviation of the population closely. To a lesser extent, it is also important to ensure that the first test level is chosen wisely. Experience with similar first element designs and/or pre-test firings can be used to estimate these values. Five samples of the allocated group can be used in initial searches for reasonable starting points and increments.

D.2.3.2 Langlie Test Procedure

The Langlie method was developed by Langlie in 1965[2]. The main goal in developing this method was to overcome the strong dependence of the efficiency of the Bruceton test on the choice of the step size. Analysis and experience had shown that the step size of the Bruceton test had to be correct to within a factor of 2 for reliable results.

The Langlie test requires the experimenter to specify lower and upper stress limits. The first test is conducted at a level midway between these limits. The remaining levels can be found by the prescription given by Langlie: "The general rule for obtaining the $(n+1)^{st}$ stress level, having completed n trials, is to work backward in the test sequence, starting at the n^{th} trial, until a previous trial (call it the p^{th} trial) is found such that there are as many successes as failures in the p^{th} through n^{th} trials. The $(n+1)^{st}$ stress level is then obtained by averaging the n^{th} stress level with the p^{th} stress level. If there exists no previous stress level satisfying the requirement stated above, then the $(n+1)^{st}$ stress level is obtained by averaging the n^{th} stress level with the lower or upper stress limits of the test interval according to whether the n^{th} result was a failure or success."

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[1] Dixon, J. W., and Mood, A. M. (1948), "A Method for Obtaining and Analyzing Sensitivity Data," *Journal of the American Statistical Association*, **43**, 109-126.

[2] Langlie, H. J. (1965), "A Reliability Test Method for `One-Shot' Items," Technical Report U-1792, Aeronautical Division of Ford Motor Company, Newport Beach, California.

The Langlie test has been shown to be less susceptible to variations in efficiency caused by inaccurate test design. The efficiency of the test is somewhat dependent on the choice of lower and upper stress limits. Most users specify limits that are extremely wide to avoid the situation where the limits are too close together, or do not contain the region of interest. The method is most efficient if the upper and lower limits are ±4 standard deviations from the mean.

One problem with the test method, however, is that the method concentrates the test levels too close to the mean, resulting in inefficient determination of the standard deviation of the population.

D.2.3.3 The Neyer D-Optimal Test Procedure

The Neyer D-Optimal test[3] was designed to extract the maximum amount of statistical information from the test sample. Unlike the other test methods, this method requires detailed computer calculations to determine the test levels. The Neyer D-Optimal test uses the results of all the previous test results to compute the next test level.

The Neyer test has three parts. The first part of the new test algorithm is designed to "close in" on the region of interest (to within a few standard deviations of the mean) as quickly as possible. The second part of the test is designed to determine unique estimates of the parameters efficiently. The third part of the test continuously refines the estimates once unique estimates have been established.

The Neyer test requires the user to specify three parameters, lower and upper limits, and an estimate of the standard deviation. The first two parameters are used only for the first few tests (usually two) to obtain at least one fire and one failure. The estimate of the standard deviation is used only until overlap of the data occurs. Thus, the efficiency of the test is essentially independent of the parameters used in the test design.

D.2.4 Comparison of Test Methods

There is no unambiguous method of ranking the test methods. A good test method should yield estimates of the parameters of the population that are accurate and precise. All of the test methods yield accurate parameters on average. Thus, the best way to characterize the tests is by their precision. The purpose of most sensitivity tests is to determine an all-fire or a no-fire level. These levels are usually defined as that level at which at least 0.999 of the devices fire (all-fire) or at which no more than 0.001 of the devices fail to fire (no-fire). (Other probability levels are sometimes required.) With the assumption of normality, the all-fire and no-fire levels can be converted into a simple function of the mean, μ, and the standard deviation, σ, of the population. The 0.999 all-fire level is $\mu+3.09\ \sigma$, and the no-fire level is $\mu-3.09\ \sigma$. Thus, precise determination of the all-fire or no-fire level requires precise determination of the mean, and especially the standard deviation.

There are several ways to compare the ability of the various test methods to precisely determine estimates of the standard deviation. One method would be to determine the variation of the estimates of the standard deviation as a function of sample size and test method. This variation depends not only on the test method, but also on the experimenter's guess of the parameters of the population before beginning the test.

The efficiency of the Bruceton test is strongly dependent on the choice of step size. The efficiency of the Langlie test is somewhat dependent on the spacing between the upper and lower test levels. The Neyer D-Optimal test is essentially independent of the choice of parameters.

A good estimate of the standard deviation is known before the test for many devices. If the devices are well characterized from previous tests, the standard deviation may be known to approximately a factor of 2.

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[3] Neyer, B. T. (1994), "A D-Optimality-Based Sensitivity Test," TECHNOMETRICS, **36**, No 1, Pages 61-70.

Figure D.1 shows the variation of the estimates of the standard deviation as a function of the sample size for the three test methods under the assumption that the standard deviation is well-known before start of testing. The figure also assumes that the parameters of the test were optimized for the population.

Figure D.1 also shows that variation of the estimate of the standard deviation has a strong dependence on the test method chosen. For example, a 20-shot Bruceton test yields a relative variance of 66%, while the Langlie test yields a variance of 28 % and the Neyer D-Optimal yields a variance of 20%. The paper by Neyer (1994) gives greater details of the analysis used to produce such graphs as well as additional graphs.

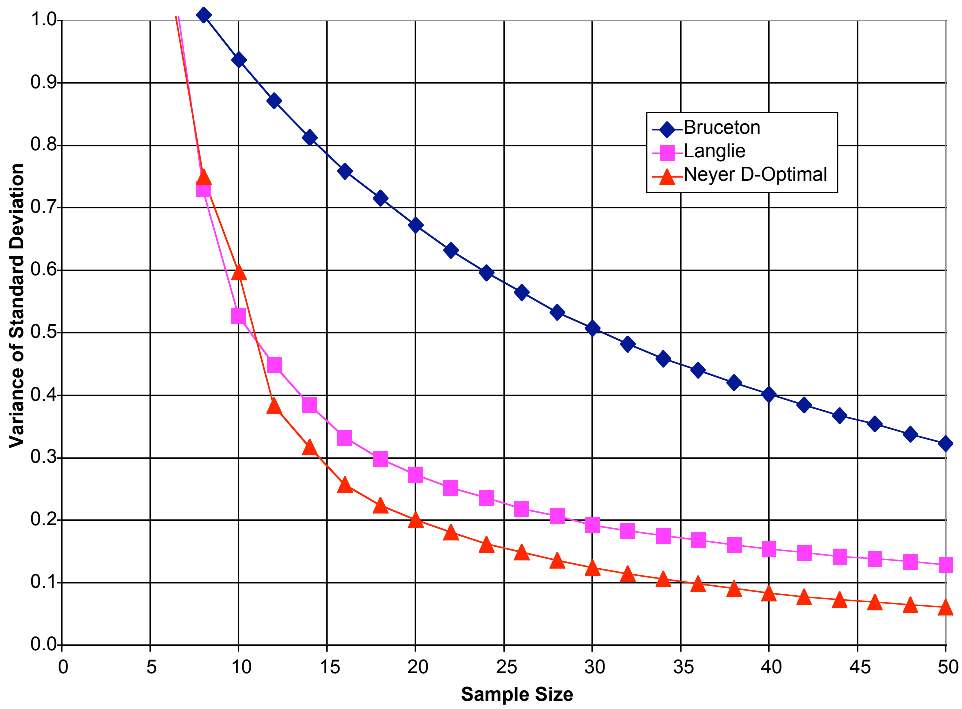

Figure D.1 — Comparison of the Variation in Estimates of the Standard Deviation

Another method of judging the utility of the various test methods is to determine the extreme values of the estimates of a parameter. The greatest concern to the design engineer in conducting and analyzing sensitivity tests is the tendency of the method to produce estimates of the parameters that are far removed from the true parameters.

Figure D.2 shows the 5% and 95% values of the standard deviation as a function of sample size for the three test methods. Also shown in the figure are the corresponding curves for the F Test.

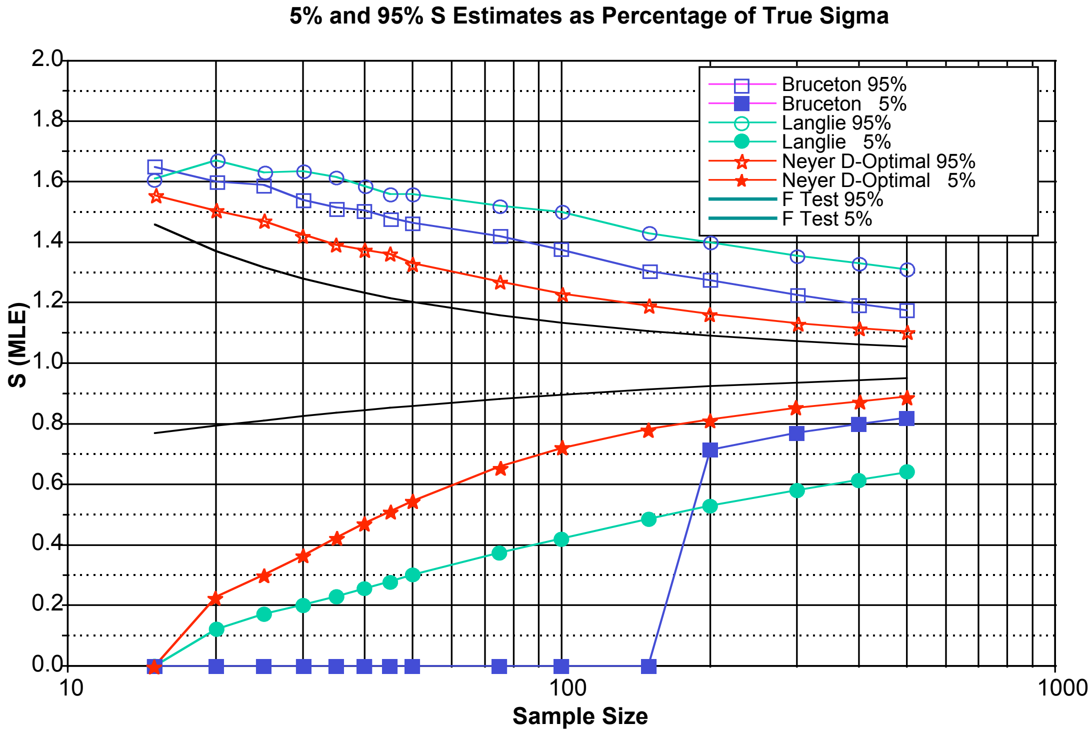

Figure D.2 — 5% and 95% Estimates of the Relative Standard Deviation

The figure illustrates several important points. The first is that it is extremely difficult to establish the value of the standard deviation to great precision with a limited sample size. For example, with a sample size of 150 (much greater than is typically used in practice) 5% of the estimates of the standard deviation will be more that 20% lower than the true value and 5 % of the estimates will be more than 20% higher than the true values for the Neyer D-Optimal tests. For the same sample size for the Langlie test, 5% would be 50 % lower, and 5% would be 45% higher. For the Bruceton test the corresponding results are 100% lower, and 30% higher.

For the typical sample size used in threshold tests in the explosive community 20–50, it is impossible to estimate the standard deviation, and thus the all-fire and no-fire levels, with great certainty. Thus, in addition to the estimation of the parameters of the population, it is also imperative that the appropriate analysis be performed to estimate the confidence of the estimate of the parameters. Confidence estimation is discussed in the next section.

The F Test curves shown in Figure D.2 show how much less information is available for sensitivity tests compared to standard statistical tests. The F Test is used in standard statistical testing to calculate the fraction of estimates of the standard deviation that are higher or lower than a given value. If it were possible to measure the exact threshold of individual devices, then the estimates of the standard deviation would be governed by the F Test. Inspection of the curves shows that a sensitivity test requires a sample size many times greater than the sample size of a classical statistical test to achieve the same range of values for the standard deviation.

The final important point illustrated by the figures is that the ability to determine reasonable estimates of the parameters is extremely dependent on the test method chosen to conduct the test. Both Figure D.1 and Figure D.2 illustrate the importance of choosing an efficient test method when conducting sensitivity tests.

D.2.5 Reliability and Confidence Levels

Reliability and confidence level values conventionally used in sensitivity tests and analysis requirements are 0.999 and 95%, respectively. This is literally interpreted to mean that the designer is 95% confident that no more than 1 in 1000 first elements will fail to function at the estimated all-fire rating.

A 95% confidence requirement is typical in the statistical world. The 95% confidence level literally means that the level that is computed will be right 95 % of the time. Some manufacturers have been known to specify 50% confidence bands. Such values will be wrong at least half of the time. *Whenever a sensitivity test is required, a confidence of 95% should be specified.*

A wise manufacturer will add margin to these values to ensure that reliability is far greater. Likewise the ignition stimulus delivered to the first element in the end application should not be limited to the all-fire rating. Explosive system reliability assessments should therefore use the minimum stimulus values of the ignition system to compute a more realistic reliability value for use in system level analysis.

D.3 Analysis Methods

More methods of analyzing the results of sensitivity tests have been proposed than have test methods. The method chosen to analyze the data of the test is at least as important as the test method. While many analysis methods can be used to analyze the results of any test method, other analysis methods are designed to analyze only one test design. All of the analysis methods do a good job of estimating the parameters of the population, i.e. the estimate of the mean, *M*, is close to the true mean, μ, and the estimate of the standard deviation, *S*, is close to the true σ. However, the ability of the various methods to compute reliable confidence levels varies greatly.

The variance function method assumes that the variances of *M* and *S* can be estimated by simple functions of the sample size and the standard deviation. These functions are generally dependent on the initial conditions, sample size, and the test design (the type of test—Langlie, Bruceton, etc.). There are three methods used to compute confidence intervals for the mean, the T test, the Chi Squared, or F tests. However, these generalized statistical methods should not be used. The assumptions that are used to construct the general statistical tests are violated in the case of sensitivity tests. Figure D.2 shows the curves for both the F test as well as curves for the various sensitivity tests. The figures clearly show that the F test cannot be used to analyze sensitivity tests.

The simulation method uses simulation to determine the variance of the parameters after the test has been completed. This method can provide reliable estimates of the variances *as long as the simulation is carried out with parameterization relevant to the population*. If simulation is used to estimate the variation of the parameters, the parameters for the simulation must span a wide area around the estimates from the test data. The number of simulation runs must be sufficient (over 1000) to ensure that the results are statistically valid.

The Cramer-Rao method is used by programs such as ASENT and in the calculations of the variance in the Bruceton method. ASENT is discussed further in the next few sections.

Simulation discussed in some of the referenced papers shows that the variance of both *M* and *S* scales approximately with σ^2. Because σ^2 is not independently known, all of the previously mentioned techniques base their estimates on the maximum likelihood estimate of σ, *S*. If the successes and failures do not overlap, $S = 0$ and these methods fail to produce estimates for confidence regions for both *M* and *S*. The Likelihood Ratio Method can produce reliable confidence interval estimates in all cases, including this degenerate case.

Almost all of the analysis methods used to date produce false confidence. That is, what is reported as a 95% confidence level is in actuality more like a 60% confidence level. *Thus, the design agency should specify the analysis method to be used.* The analysis method should be one that has been shown to produce realistic confidence levels.

Permanent records of test data, computations and results should be retained as permanent parts of the first element documentation package.

D.3.1 Bruceton Analysis

The Bruceton test was designed so that it would be possible to use simple paper and pencil calculations to determine the mean, the standard deviation, as well as estimates of their variance. This analysis procedure was designed before the invention of electronic computers. Today, more reliable analysis methods are available to analyze the data. This analysis method can only be used to analyze Bruceton tests, and only if the number of test levels are between 4 and 6, and the sample size is at least 40. In such a case, the results would be essentially identical to the ASENT method described in the next section. *In all cases it would be preferable to use a more reliable analysis method.*

D.3.2 ASENT Analysis

The ASENT computer software is in use at many laboratories around the world. Although this is the analysis method usually associated with the Langlie test method, it can analyze the results of tests conducted according to any test method. The analysis method computes the maximum likelihood estimates of the parameters. It computes estimates of the variance of the parameters by computing the curvature of the likelihood function. This analysis method gives the correct results asymptotically. It will not analyze the results of a test where the successes and failures do not overlap. It gives reliable results if the sample size is greater than 200.

D.3.3 Likelihood Ratio Test

The likelihood ratio method is used by the software MuSig in use at many laboratories around the world. Although this is the analysis method usually associated with the Neyer test method, it can analyze the results of tests conducted according to any test method. The analysis method computes the maximum likelihood estimates of the parameters. It computes estimates of the variance of the parameters by using the likelihood ratio test. This analysis method gives the correct results asymptotically. It will analyze the results of any test, even if the successes and failures do not overlap. It gives reliable results if the sample size is greater than 20.

D.3.4 Comparison of Analysis Methods

The two most widely used general analysis methods can be compared in a number of ways. The most meaningful way to compare the methods is to determine what fraction of the time the true parameters are outside of the specified confidence region. A properly computed 95% confidence region, for example, should contain the true parameters approximately 95% of the time. Figure D.3 shows the fraction of parameters outside a given confidence region for both the asymptotic analysis used by ASENT and the likelihood ratio analysis used by MuSig. This figure is for a sample size of 30, for the Bruceton, Langlie, and Neyer D-Optimal tests. Other similar figures can be found in the paper by Neyer (1992)[4]. The solid line in the figure is what a perfect analysis method would produce.

The figure clearly shows that both of the analysis methods produce false confidence. For example, for a nominal 95% confidence region, the likelihood ratio test has the parameters outside of the confidence region approximately 8% of the time. While this is more than the 5% expected for a true 95% confidence region it is close to the requested confidence. The design engineer could specify a slightly more restrictive confidence (such as 97%) to achieve the required 95% confidence region.

The asymptotic 95% confidence region however, has the parameters outside of the confidence region approximately 20% of the time. To achieve a true 95% confidence region using this analysis method would require the computation of a confidence region greater than 99%.

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[4] Neyer, B. T. (1992), “An Analysis of Sensitivity Tests,” Technical Report MLM-3736, EG&G Mound Applied Technologies, Miamisburg, OH.

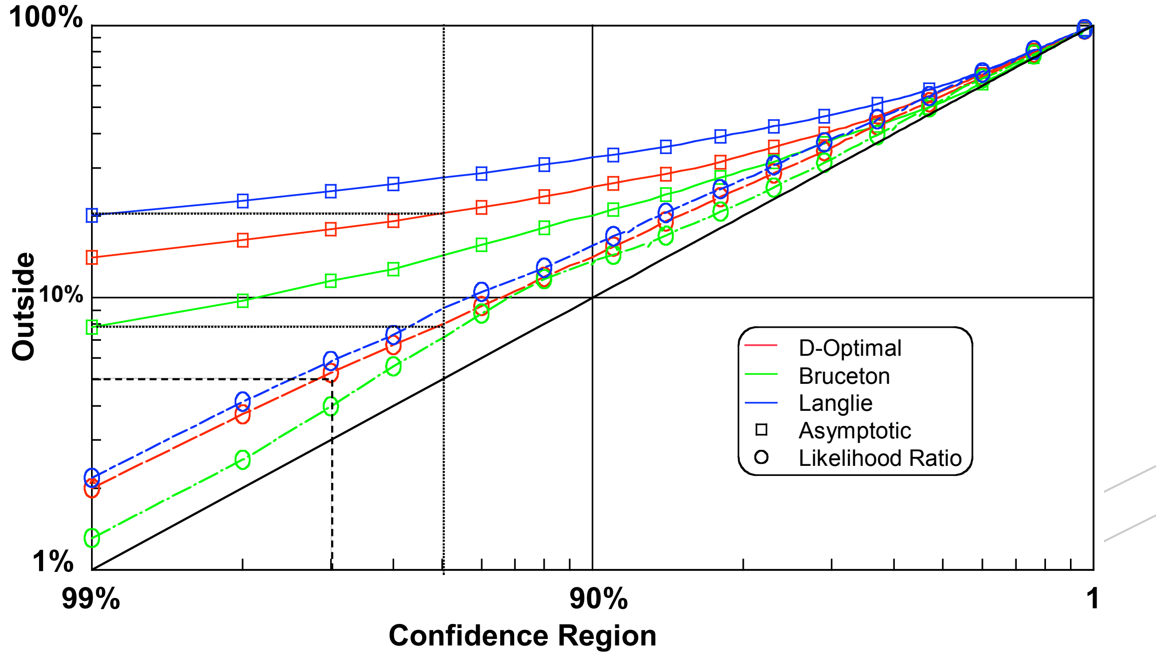

Figure D.3 — Comparison of Confidence Likelihood Ratio versus ASENT

Devices that are considered qualified when analyzed according to one analysis method could be unqualified when analyzed according to a more exact analysis method such as the likelihood ratio test. Thus, *the design engineer should specify the analysis method*. If a true 95% confidence region is required, then only analysis methods capable of producing a realistic confidence region should be allowed.

Bibliography

[1] AIAA-2005-4039, *Advanced Applications of Statistical Methods in Testing of Energetic Components and Systems*

[2] MIL-HDBK-83578, *Criteria for Explosive Systems and Devices Used on Space Vehicles*

[3] MIL-STD-810F(3), *Environmental Engineering Considerations and Laboratory Tests*